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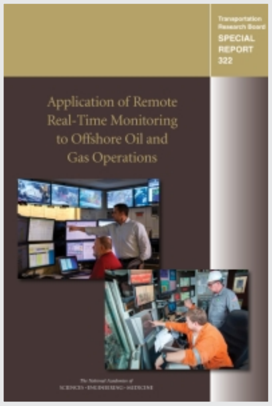

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TRANSPORTATION RESEARCH BOARD
SPECIAL REPORT 322

Application of Remote Real-Time Monitoring to Offshore Oil and Gas Operations

Committee on the Application of Real-Time Monitoring of Offshore Oil and Gas Operations

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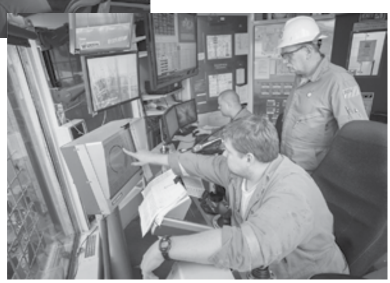

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This report has been reviewed by a group other than the authors according to the procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the National Academy of Medicine.

This study was sponsored by the Bureau of Safety and Environmental Enforcement of the U.S. Department of the Interior.

Cover photos (*from top*): Onshore remote real-time monitoring of drilling operations; offshore team using real-time data on rig floor. (Photographs used with permission. ©2016 BP America Inc. All rights reserved.)

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Committee on the Application of Real-Time Monitoring of Offshore Oil and Gas Operations

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Preface

The Bureau of Safety and Environmental Enforcement (BSEE) of the U.S. Department of the Interior requested in July 2014 that the Marine Board of the National Research Council (NRC) conduct a study advising the agency on the use of real-time monitoring (RTM) to improve the safety and reduce the environmental risks of offshore oil and gas operations. The charge from BSEE and related background material are given in Chapter 1. Specifically, the committee was asked to address five main tasks on the use of RTM (see the statement of task, Box 1-1 in Chapter 1):

1. The critical operations and specific parameters that should be monitored from drilling and producing facilities to manage and mitigate environmental and safety risks (e.g., to reduce the risk of well kicks, blowouts, and other sources of casualties),
2. The role that automation and the use of predictive software tools should play in RTM,
3. The role that condition-based monitoring should play in RTM and how the operating equipment using condition-based monitoring could be tailored to and/or used for RTM,
4. Whether RTM should be incorporated into BSEE's regulatory scheme in either a prescriptive or performance-based manner, and
5. How BSEE should leverage RTM to enhance its safety enforcement program.

The findings and recommendations (see Chapter 4) represent the consensus effort of a committee of technical experts. Appointed by NRC, the study committee consists of 10 members from industry and academia with expertise in offshore oil and gas drilling, operations, and safety. The

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expertise of the committee members includes risk analysis, petroleum engineering, government regulations, information technology and data analysis, and operations in high-risk environments. Complete committee biographical information is provided at the end of the report. The diverse background of the committee membership proved to be valuable, since the committee had to rely heavily on its collective judgment and experience in providing its recommendations in this report.

As a central part of its remit, the committee held an industry workshop on April 20–21, 2015, in Houston, Texas. In addition, the committee met six times over a 12-month period and carefully examined the topic of remote real-time monitoring (RRTM). Several RRTM centers were visited. The committee visited Houston-area RRTM facilities for offshore drilling and met with blowout preventer manufacturers, service companies, and operating companies to gain insights into the applications of RTM. During the final stage of the report review process, BSEE released its final Blowout Preventer Systems and Well Control rule.[1] Given the timing of the release, the committee was unable to include additional information about this rule in its final report. The report that follows represents the consensus opinions of the committee members and presents the committee's findings and recommendations on the use of RRTM by the offshore oil and gas industry and by BSEE.

ACKNOWLEDGMENTS

The committee thanks the many individuals who contributed to its work. Specifically, the committee acknowledges John Cushing, Julie Conklin, and the other staff members of BSEE. The work of the committee was facilitated by the thoughtful advice and background information provided by all of the presenters at its meetings and workshop and by industry officials who provided insights during the course of the study. To seek additional information on and a better understanding of the operations of RRTM, the committee visited several centers in the Houston area, including those belonging to BP, Chevron, Shell, Anadarko, and Schlumberger.

[1] The final rule is available at https://www.gpo.gov/fdsys/pkg/FR-2016-04-29/pdf/2016-08921.pdf.

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In addition, the committee met with GE Oil and Gas, National Oilwell Varco (NOV), Ashford Technical Services, and Pulse Structural Monitoring.

The committee received presentations and briefings from the following individuals, whom it thanks: Doug Morris, BSEE; John Cushing, BSEE; Mark Anderson, 838, Inc.; Holly Hopkins, American Petroleum Institute; Chris Harder, BP; Barry J. Gaston, Shell; Todd Durkee, Anadarko Petroleum Corporation; George Buck, Chevron; Charlie Williams, Center for Offshore Safety; Norman D. Knight, National Aeronautics and Space Administration, Johnson Space Center; Toon Bairaj-Vinichai, Chevron; Jim Grant, BP; John Sutler, BP; George Stalter, BP; Nancy Seiler, Anadarko Petroleum Corporation; Curtis Austin, Anadarko Petroleum Corporation; Susan Dwarnick, BSEE; Darryl Fett, Total E&P USA; Joseph Leimkuhler, LLOG Exploration; Lisa Grant, Noble Energy; Steven Kendrick, BHP Billiton; Dale Bradford, Murphy Oil Corporation; Anil Wadhwa, Baker Hughes; Kevin Goy, Schlumberger; Andreas Sadlier, Halliburton; Chuck Salminen, Weatherford; Lee Geiser, Petrolink; Eric van Oort, Genesis Real-Time Systems; David Stevens, Chevron; Chris Hall, Marathon Oil; Steve Bodden, Stone Energy; Amro Hamza, Anadarko; Tom Moroney, Shell; Harris Reynolds, Diamond Offshore Drilling; Jean-Paul Buisine, Transocean Offshore Deepwater Drilling; Tony Hogg, Pacific Drilling; Brian Wright, CAD Control Systems; Daniel Marquez, Athens Group; Evan Zimmerman, Offshore Operators Committee; Alan Spackman, International Association of Drilling Contractors; Anton du Preez, National Ocean Industries Association; Frank Chapman, Ashford Technical Services; Ron Brown, Ashford Technical Services; Timothy W. Turner, Schlumberger; Robert J. Alvarado, Schlumberger; Joey Rodriguez, Pulse Structural Monitoring; Silvia Gonzalez, GE Oil and Gas; Luis Huerta, GE Oil and Gas; Martha C. Saker, GE Oil and Gas; Frank Springett, NOV; Clay Simmons, NOV; Thore Langeland, Exploration and Production Information Management Association; Trond Lilleng, StatOil (submitted presentation); Norman Comstock, Berkeley Research Group; Andrew Jaffrey, Cameron Drilling Systems; Captain Andrew E. Tucci, U.S. Coast Guard; and Fred Dupriest, Texas A&M University.

This study was performed under the overall supervision of Stephen R. Godwin, Director, Studies and Special Programs, Transportation Research Board. The committee acknowledges the work and support of Mark S. Hutchins, who served as study director and assisted the committee

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in the preparation of its report. The committee also acknowledges the work and support of Karen Febey, Senior Report Review Officer, who managed the report review process. Norman Solomon edited the report; Janet M. McNaughton handled the editorial production; Juanita Green managed the production; and Jennifer J. Weeks prepared the manuscript for prepublication web posting under the supervision of Javy Awan, Director of Publications. Timothy Devlin, Claudia Sauls, and Amelia Mathis assisted with meeting arrangements and communications with committee members. The committee extends its sincere gratitude to the diligent and capable staff of the National Academies. Without their efforts and support, production of the report would not have been possible.

This report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

The committee thanks the following individuals for their review of this report: Elmer (Bud) P. Danenberger III, Independent Consultant, Reston, Virginia; Fred Dupriest, Texas A&M University, College Station; Delores M. Etter, Southern Methodist University, Dallas, Texas; W. Michael Hanemann, University of California, Berkeley; Roland N. Horne, Stanford University, California; W. Allen Marr, Geocomp Corporation, Acton, Massachusetts; R. Keith Michel, Webb Institute, Glen Cove, New York; and Donald L. Paul, University of Southern California, Los Angeles.

Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the committee's findings or recommendations, nor did they see the final draft of the report before its release. The review was overseen by Bonnie J. McCay (NAS), Rutgers University (emerita) and by Susan Hanson (NAS), Clark University (emerita). Appointed by NRC, they were responsible for making certain that an

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independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

—Richard A. Sears, *Chair*
Committee on the Application of Real-Time
Monitoring of Offshore Oil and Gas Operations

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Acronyms and Abbreviations

ALARP	as low as reasonably practicable
ANSI	American National Standards Institute
APD	Application for Permit to Drill
API	American Petroleum Institute
BAST	best available and safest technology
BOEM	Bureau of Ocean Energy Management
BOEMRE	Bureau of Ocean Energy Management, Regulation, and Enforcement
BOP	blowout preventer
BSEE	Bureau of Safety and Environmental Enforcement
CBM	condition-based maintenance
CBR	case-based reasoning
CRIOP	Crisis Intervention and Operability
CRM	crew resource management
DDRS	Daily Drilling Report System
DFU	defined hazards and accident conditions
DOI	U.S. Department of the Interior
DW	data warehouse
DWOP	Deepwater Operations Plan
E&P	exploration and production
EP	exploration plan
ETAC	Engineering Technology Assessment Center
FFRDC	federally funded research and development center
FPSO	floating production, storage, and offloading
GOM	Gulf of Mexico
HFE	human factors engineering
HSE	health, safety, and environmental

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IADC	International Association of Drilling Contractors
IEC	International Electrotechnical Commission
IPAA	Independent Petroleum Association of America
ISA	International Society of Automation
ISS	International Space Station
IT	information technology
IWC	intelligent well completions
JIP	joint industry project
JSC	Johnson Space Center
KPI	key performance indicator
LWD	logging while drilling
ML	machine learning
MMS	Minerals Management Service
MODU	mobile offshore drilling unit
MWD	measurement while drilling
NAE	National Academy of Engineering
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
NOIA	National Ocean Industries Association
NPT	nonproductive time
NRC	National Research Council
NTNU	Norwegian University of Science and Technology
OCS	outer continental shelf
OCSLA	Outer Continental Shelf Lands Act
OEM	original equipment manufacturer
OESI	Ocean Energy Safety Institute
OGP	International Association of Oil and Gas Producers
OIG	Office of Inspector General
OLF	Oljeindustriens Landsforening
OOC	Offshore Operators Committee
OT	operational technology
PESA	Petroleum Equipment Supplier Association
PINC	potential incident of noncompliance
PLC	programmable logic control
PRODML	Production Markup Language
PSA	Petroleum Safety Authority (Norway)

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R&D	research and development
RISI	Repository for Industrial Security Incidents
RNNP	Risikonivå i norsk petroleumsvirksomhet
RP	Recommended Practice
RRTM	remote real-time monitoring
RTD	real-time data
RTM	real-time monitoring
SCADA	supervisory control and data acquisition
SEMP	safety and environmental management program
SEMS	Safety and Environmental Management Systems
SINTEF	Stiftelsen for Industriell og Teknisk Forskning
SMS	safety management system
SPE	Society of Petroleum Engineers
TA&R	Technology Assessment and Research
TRB	Transportation Research Board
24/7	24 hours a day, 7 days a week
USCG	United States Coast Guard
VSAT	very small aperture terminal
WITS	Wellsite Information Transfer Specification
WITSML	Wellsite Information Transfer Standard Markup Language
XML	Extensible Markup Language

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Appendixes

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Executive Summary

The U.S. outer continental shelf is a major source of energy for the United States, and over the past 25 years, deepwater oil and gas production in the Gulf of Mexico has increased significantly. With the move into greater water depths, industry is drilling deeper wells, where operations can experience higher pressures, higher temperatures, and greater uncertainty. Remote monitoring of drilling operations could help operators and regulators enhance the safety of these operations.

This study advises the Bureau of Safety and Environmental Enforcement (BSEE) on the application and use of remote real-time monitoring (RRTM) to improve management of the safety and environmental risks of offshore oil and gas operations. As a central part of the charge (see Box 1-1 in Chapter 1), BSEE asked the committee to conduct a workshop that addressed the critical operations and parameters to be monitored in real time, the role RRTM could play in automation and predictive software and condition-based maintenance (CBM), and how RRTM could be leveraged by BSEE and incorporated into its regulatory framework.

Drillers have monitored drilling operations offshore in real time for decades; more recently, a few operators have also transmitted some of these data onshore to improve efficiency and risk management. During its information gathering, the committee was told that RRTM's benefits include increased efficiency, decreased downtime and operational disruptions, reduced equipment damage, improved safety, and overall reduction in risk.

Whereas RRTM can provide the rig with technical support and access to onshore expertise, during the committee's workshop the U.S. industry expressed a belief that responsibility and authority for operational decision making should remain offshore. Situational awareness on the

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offshore facility is important, and RRTM data do not always provide the necessary context.

The use of RRTM is variable across the offshore oil and gas industry, and diverse RRTM technologies are available. No RRTM industry standard or standard practice exists, and the industry exhibits varying levels of maturity in its use of RRTM. Thus, a standard approach is not likely to work or to be needed for every company or every well.

The committee views RRTM as a best available and safest technology (BAST), when such technologies are consistent with the principles of ALARP (as low as reasonably practicable). The director of BSEE establishes BAST through a documented process, but determining RRTM as BAST in some contexts would not mandate its use across the board. The decision to use RRTM occurs when such technologies are available and economically feasible. BSEE could use existing regulatory requirements, such as the Application for Permit to Drill (APD) and the Safety and Environmental Management System (SEMS) plan, to advance appropriate use of RRTM. By encouraging offshore operators to address RRTM in their APD or SEMS plans, BSEE could allow operators to determine the circumstances under which RRTM should be used and challenge them to do so when BSEE believes that RRTM is necessary for managing risk.

RRTM information—whether in real time or archived—could also benefit BSEE in its inspection activities and support inspectors' review of safety-related information before they visit offshore facilities. Preparation, prioritized by risk, could allow for more efficient scheduling and effective execution of BSEE inspections.

The committee is not in a position to recommend or validate a definitive list of critical operations and parameters for RRTM. In the committee's judgment, a single standard list for all operations is not practical in view of the variability in operating conditions, geology, and scope and scale of facilities; the evolution of technology; consideration of human factors; and the incorporation of RRTM in a risk-based approach to regulating offshore operations. However, companies using RRTM appear to monitor some of the same critical operations and parameters (see Chapter 2).

As sensor technology advances and the ability to transmit that data improves, issues with regard to the management of massive volumes of real-time data will grow. Likewise, as more RRTM of offshore operations

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is introduced, cybersecurity risks associated with the increased use of technology will rise. Control systems for critical rig-based equipment, not originally designed for connectivity to Internet-facing systems, are likely be at risk.

RRTM could contribute to achieving a longer-term goal of offshore systems CBM. Blowout preventers (BOPs) provide a promising case. However, before CBM can go forward, BOP operational data and maintenance history will need to be collected and stored continually over the lifetime of the equipment to allow development of predictive models. Retroactive analysis of BOP performance data may not be adequate due to the complexity and variability of offshore operations and incomplete BOP maintenance history.

The committee's consensus recommendations, which are listed below and elaborated in Chapter 4, provide guidance to BSEE and stakeholders in addressing the issues associated with the application of RRTM to offshore oil and gas operations.

Recommendation 1. BSEE should pursue a more performance-based regulatory framework by focusing on a risk-based regime that allows industry to determine relevant uses of RRTM on the basis of assessed levels of risk and complexity. BSEE could assess decisions about the monitoring of well parameters or the application of RRTM through the review of a company's APD or SEMS plans and challenge the company to apply RRTM to manage the risk of complex operations.

Recommendation 2. The committee views RRTM as BAST when justified by the risk of particular wells. **BSEE should monitor the spectrum of RRTM technologies and best practices by using either an internal BSEE group, such as the agency's proposed Engineering Technology Assessment Center, or an external organization, such as the Ocean Energy Safety Institute.**

Recommendation 3. Consistent with recommendations of previous committees of the National Academies (NAE and NRC 2012; NAE and NRC 2013), **BSEE should encourage involvement of all stakeholders in the development of risk-based goals and standards governing offshore oil and gas processes. Specifically, BSEE should work with the American Petroleum Institute (API), the International Association of Drilling**

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Contractors, and other relevant stakeholders to form an API standing technical committee (as opposed to an ad hoc committee) that would establish minimum requirements for which critical operations (and parameters) are monitored and for which data are collected and monitored in real time. In addition, BSEE, along with this technical committee, should propose standards for communication protocols between onshore and offshore facilities when RRTM is used.

Recommendation 4. BSEE should encourage API to work with original equipment manufacturers, drilling contractors, and industry trade associations to establish a BOP CBM pilot project, with the goal of an API publication.

REFERENCES

Abbreviations

NAE	National Academy of Engineering
NRC	National Research Council

NAE and NRC. 2012. *Macondo Well* Deepwater Horizon *Blowout: Lessons for Improving Offshore Drilling Safety*. National Academies Press, Washington, D.C. https://www.nae.edu/Publications/Reports/53926.aspx.

NAE and NRC. 2013. *Best Available and Safest Technologies for Offshore Oil and Gas Operations: Options for Implementation*. National Academies Press, Washington, D.C. http://www.nap.edu/download.php?record_id=18545.

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1

Background

Under the authority granted by the Outer Continental Shelf Lands Act and subsequent amendments passed in 1978,[1] the Bureau of Safety and Environmental Enforcement (BSEE)[2] works to promote safe and environmentally responsible activity for oil and natural gas exploration, development, and production operations in U.S. federal waters. Over the past 30 years, BSEE, with support from industry, has sought to improve the safety and oversight of offshore oil and gas operations by applying new technologies and implementing more robust safety management systems, including the American Petroleum Institute's (API's) Recommended Practice (RP) 75—a comprehensive safety and environmental management program initially released in 1993.

In the aftermath of the Macondo well blowout and *Deepwater Horizon* mobile offshore drilling unit (MODU) explosion[3] in April 2010, BSEE has developed a mission statement and set of strategic goals[4] to underpin its oversight and enforcement role and to enhance the safety of offshore oil

[1] See Public Law 95-372 as amended on September 18, 1978 (http://www.gpo.gov/fdsys/pkg/STATUTE-92/pdf/STATUTE-92-Pg629.pdf).

[2] Initially, oversight authority rested with the U.S. Geological Survey. The Minerals Management Service (MMS) had authority for offshore oil and gas operations from 1982 to 2010. In June 2010, MMS was renamed the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE). On October 1, 2011, the U.S. Department of the Interior reorganized BOEMRE and established two new, independent bureaus—BSEE and the Bureau of Ocean Energy Management (BOEM).

[3] For background on the blowout and explosion, see Presidential Commission 2011 and NAE and NRC 2012.

[4] The mission statement and strategic goals are available at http://www.bsee.gov/WorkArea/DownloadAsset.aspx?id=85899347070.

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and gas operations. The agency began urging industry to make a deeper commitment to a strong culture of safety in all its operations (*Federal Register* 2013) and to move toward a more risk-based safety regulatory program by passing the Safety and Environmental Management Systems (SEMS) regulations[5] in 2010 and 2013. These regulations mandated the previously voluntary API RP 75 and moved beyond a prescriptive system that encouraged compliance through checklists of potential incidents of noncompliance. Over the past 3 years, BSEE has sought improvements in implementing its mandate for the use of emerging technologies and best available and safest technology (BAST).[6] BSEE has attempted to bolster its risk-based regulatory program by identifying initiatives such as risk-based inspections, a near-miss and failure reporting system, and real-time monitoring (RTM) of offshore facilities.[7] BSEE expects these initiatives—especially RTM—to help decrease many of the risks associated with and allow more effective oversight of offshore oil and gas development. Some industry representatives have agreed that focused remote RTM (RRTM) of exploration and production facilities could help to decrease some of the risks associated with offshore oil and gas operations (TRB 2015). As part of its evaluation and implementation of emerging technologies and BAST, BSEE has proposed hiring qualified staff for its new Engineering Technology Assessment Center, which would evaluate innovative technologies and proposed industry standards and provide engineering expertise necessary for developing offshore oil and gas regulations (DOI 2015, 9–10). The current BSEE hybrid regulatory model incorporates both prescriptive and performance elements. Before any new BSEE initiatives, such as RTM, can be integrated into its regulatory program, the agency will need to decide on the structure of a new regulatory model. Improved communication with stakeholders will be necessary to prevent contradictory signals and practices.

[5] See SEMS regulations in Subpart S (http://cfr.regstoday.com/30cfr250.aspx#30_CFR_250pSUBPART_S); see also TRB 2012.
[6] See NAE and NRC 2013.
[7] D. Morris, BSEE, presentation to the committee, December 2014; S. Dwarnick, presentation to the committee at the Houston workshop, April 2015.

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BSEE PRIORITIES AND CURRENT STATUS

As one of its top objectives and on the basis of recommendations from external investigative reports on the *Deepwater Horizon* MODU explosion (OIG 2010; Presidential Commission 2011; NAE and NRC 2012),[8] BSEE initiated exploration of how RTM and its associated technologies could transform the agency's safety and environmental oversight of offshore operations. BSEE's RTM initiative examined industry use of and experience with RTM, potential benefits of the use of RTM by BSEE, and many of the implementation challenges of incorporating RTM into the regulatory framework (BSEE 2014). BSEE also commissioned an external study to provide a broad industry overview of the use of RTM (see 838, Inc. 2014). These and other studies provided BSEE with internally and externally generated recommendations for developing its own use of RTM. The recommendations ranged from limited application of RTM as a tool for improving inspections to its constant use in monitoring high-risk offshore operations. Lessons and key conclusions from these previous studies are examined in Chapter 2.

BSEE is aware that RTM and its related technologies are advancing at a rapid pace, and the agency believes that RTM technologies could provide access to more timely data that would permit the agency to improve identification and assessment of risks and would allow for more focused inspections.[9] BSEE also considers RTM technologies and "risk-based inspection criteria" as a way to supplement and improve its offshore safety program (DOI 2015, 11) by integrating RTM with an enhanced SEMS and allowing the agency to prioritize which inspections and SEMS audits it should observe (DOI 2015, 8–9). Despite the opportunities for the management of safety in offshore operations, BSEE realizes that it must consider the implications of these RTM technologies for BSEE's regulatory and oversight role.

[8] In particular, see Recommendation 18 of OIG 2010 and Recommendations 3.4 and 3.5 of NAE and NRC 2012.

[9] S. Dwarnick, presentation to the committee at the Houston workshop, April 2015.

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RTM AND OFFSHORE OIL AND GAS OPERATIONS

For several decades, the U.S. outer continental shelf (OCS) has been a major source of energy for the United States. Over the past 25 years, deepwater development has increased significantly. Deepwater oil production, as a percentage of all oil produced in the Gulf of Mexico, increased from 4 percent in 1990 to more than 80 percent in 2014, or from roughly 12 million barrels to more than 400 million barrels annually.[10] BSEE reports that there are approximately 3,000 offshore facilities (MODUs and production platforms) operating on the OCS within U.S. federal waters (up to 200 miles offshore).[11]

Deepwater drilling and production operations on the OCS can be more complex than shallow-water or land-based drilling and can increase safety and environmental risks. In addition to moving into greater water depths, industry is drilling deeper wells offshore, where operations can experience higher pressures, higher temperatures, and greater uncertainty. Industry must manage these operations in a safe and environmentally responsible way, while BSEE must fulfill its mandate for enforcing offshore safety and environmental regulations on the OCS.

Monitoring of basic sensor data and equipment on the MODU has been an important part of safe drilling operations for some time. Advances in technology have improved the ability to capture data, which can be used for trend analysis and anomaly detection on the MODU. Improvements in telecommunications technology have allowed for data transmission to other locations, data aggregation from multiple sources, and data analysis—all while permitting remotely located staff to view real-time data and to engage with offshore personnel. The ability to collect and manage data through centralized onshore facilities has also allowed many contractors to provide enhanced services to the industry (Booth 2009). Operators and contractors have used on-site (on the rig) real-time data, such as surface measurements and downhole tool readings, to monitor

[10] See http://www.data.bsee.gov/homepg/data_center/production/production/summary.asp. BSEE defines deepwater as water depth greater than 1,000 feet.

[11] D. Morris, BSEE, presentation to the committee, December 2014. A more recent count indicates that there are about 2,300 offshore facilities; data are available at https://www.data.boem.gov/homepg/data_center/leasing/WaterDepth/WaterDepth.asp.

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dynamic drilling processes for decades. More recently, a few major operators have incorporated enhanced onshore RTM (that is, RRTM) as part of their standard management practices.[12]

The business case for RRTM of drilling operations has generally been based on increased efficiencies and improved risk management through better operational planning and execution (Laurens and Kales 2014). The remote centers in operation today are staffed by highly experienced technicians, most with offshore experience, who monitor wells and communicate directly with offshore facilities through formal and informal protocols. This arrangement provides an additional level of risk management (see Booth 2010).

Offshore personnel have the primary responsibility and accountability for decision making for all drilling operations, and industry representatives have indicated the importance of situational awareness for offshore personnel on the MODU.[13] During drilling operations, remote monitoring centers can focus on abnormal trends or well events. The centers provide an additional set of eyes for the MODU. They offer advice, support, and improved access to onshore technical expertise and allow offshore personnel to concentrate on drilling operations. If offshore personnel encounter operational issues requiring assistance or subject matter expertise, RRTM allows quick worldwide collaboration with specialists, engineers, and managers who can remain onshore. In addition, remote centers can verify the validity of incoming information streams and allow for the development of a knowledge base and for long-term data analysis. At the committee's first meeting, a Shell representative reported that RTM "improves HSE [health, safety, and the environment], reduces subsurface NPT [nonproductive time], and facilitates operational excellence." He also stated that RTM is a support tool that "improves the operator's ability to effectively manage its leases."[14]

[12] G. Buck, Chevron, presentation to the committee, December 2014.

[13] Although it is defined in many ways, situational awareness generally means knowing what is going on around you. According to the U.S. Coast Guard, "Situational Awareness is the ability to identify, process, and comprehend the critical elements of information about what is happening to the team with regards to the mission" (https://www.uscg.mil/auxiliary/training/tct/chap5.pdf). See the section on terms and assumptions below.

[14] B. Gaston, Shell, presentation to the committee, December 2014.

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At present, RRTM centers are operated primarily by the larger companies. To be effective, these centers require staff who can independently monitor several offshore wells, recognize anomalies, and engage constructively with offshore and onshore staff. Technicians meeting this description are always in demand. Other companies may use some elements of RTM, but many of these operators have expressed concerns with regard to the cost and practicality of the continuous collection of data and monitoring of all drilling operations by an onshore staff. Furthermore, if a larger number of operating companies attempted to set up 24-hours-a-day, 7-days-a-week RRTM centers, staffing them with people who have the requisite offshore experience might become more difficult.

STUDY OBJECTIVE AND CHARGE

The U.S. federal government has regulated the offshore oil and gas industry for decades. The *Deepwater Horizon* incident in 2010 was a landmark event that caused BSEE to rethink its approach to offshore safety regulation. To enhance its mandate for enforcing offshore safety and environmental regulations, in July 2014 BSEE requested that the Marine Board of the National Research Council conduct a study advising the agency on the use of RTM to improve the safety and reduce the environmental risks of offshore oil and gas operations. BSEE believed that RTM technology could transform its ability to conduct safety and environmental oversight of offshore operations. The charge of the committee is shown in Box 1-1. As a central part of its remit, BSEE asked the committee to conduct a workshop on the use of RTM systems by industry and government.

In discussions concerning the statement of task at the committee's first meeting in December 2014, the sponsor confirmed that the workshop agenda and summary report (see TRB 2015) and the committee's final report would focus on the Gulf of Mexico region, would address the five issues listed in the statement of task, and would be informed by the two reports (BSEE 2014 and 838, Inc. 2014) mentioned in the statement of task and discussed in Chapter 2. Because conduct of the Houston workshop was such an important component of the committee's statement of task, this final report draws heavily from presentations and discussions held at that workshop.

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BOX 1-1

Statement of Task

An ad hoc committee will conduct a study to advise the Bureau of Safety and Environmental Enforcement (BSEE), U.S. Department of the Interior, on the use of real-time monitoring systems (RTM) by industry and government to reduce the safety and environmental risks of offshore oil and gas operations. As part of its efforts, the committee will organize and hold a public workshop that is informed by a recently released BSEE external technical report on RTM for oil and gas operations and the preliminary findings from an internal BSEE RTM workgroup.

The committee will develop the workshop agenda, select and invite speakers and discussants, and moderate the discussions. Subsequently, the committee will (1) issue an interim report summarizing the presentations and discussion at the workshop and any findings the committee draws from the event and from the BSEE technical report; and (2) hold additional meetings to develop and provide a final report with findings and recommendations on the use of RTM by the offshore oil and gas industry and BSEE that address the five issues below. Specifically, the final report shall address

1. The critical operations and specific parameters that should be monitored from drilling and producing facilities to manage and mitigate environmental and safety risks (e.g., to reduce the risk of well kicks, blowouts, and other sources of casualties),
2. The role that automation and the use of predictive software tools should play in RTM,
3. The role that condition-based monitoring should play in RTM and how the operating equipment using condition-based monitoring could be tailored to and/or used for RTM,
4. Whether RTM should be incorporated into BSEE's regulatory scheme in either a prescriptive or performance-based manner, and
5. How BSEE should leverage RTM to enhance its safety enforcement program.

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TERMS AND ASSUMPTIONS

The statement of task (Box 1-1) mentions both drilling and production operations but does not distinguish between them. In approaching its charge, the committee differentiated between drilling operations, which are more dynamic and fluid, and production operations, which are more constant. In addition, the committee believes that clarification of the following terms relevant to its statement of task is important:

- **Real time** and **real-time data** are terms characterizing data that are reported at (or near) the time during which a process or event occurs, usually at the same time it happens—as opposed to being reported after an extended delay. "Real time" is a flexible term with varied definitions, and its use depends on the specific application. The speed of the relevant network is important, but there is not a strict speed threshold or an a priori fixed standard for deciding whether a system is in real time.
- **Real-time monitoring** is a process through which operational personnel can review, evaluate, and adjust data on a database or a system (such as offshore drilling, well completions, or production). RTM allows operational personnel to review the overall processes and functions performed on the data in real time. Typically, RTM software or an RTM system provides visual insights into the data, which can be collected from multiple or various sources on the MODU. RTM can also provide instant notifications or alerts concerning specific data-driven or administrator-specified events, such as when a data value goes out of a specified range.
- **Remote real-time monitoring:** Personnel on the MODU have monitored critical data in real time for decades. As telecommunications technology advanced, data could be monitored in real time at a remote location, which is typically an onshore office of the operating company or service contractor. In the statement of task, the term real-time monitoring (RTM) is used, but it appears to refer to *remote* real-time monitoring (RRTM). In this report, RTM will be used in referring generally to monitoring data and operations in real time or in referring to the statement of task or to the BSEE internal report, since that is the acronym used in those places. However, in addressing the key aspect of the committee's work, RRTM will be used when the report is specifically discussing *remote* real-time monitoring.

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- **Condition-based maintenance** (CBM), also known as predictive maintenance, is an approach to performing maintenance actions on the basis of the condition of a component as measured or predicted by diagnosing its state of health, detecting and isolating failure modes, and estimating the component's remaining useful life. This differs from the approach of scheduling maintenance actions at planned times at which the component is replaced regardless of its actual condition. CBM uses real-time data to prioritize and optimize maintenance resources. With the increase of equipment instrumentation, advancements in communications technology, and the availability of better tools for analyzing condition data, maintenance personnel can determine an appropriate time to perform maintenance on a component or piece of equipment by developing more accurate models of equipment health and degradation. In the statement of task, the term "condition-based monitoring" is used to refer to condition-based maintenance. In this report, the term "condition-based maintenance" will be used.
- **Technology.** This report uses the term technology broadly to encompass both the equipment involved in offshore operations and the control and human systems that are deployed with the equipment.
- **Situational awareness** is a term that implies a high degree of knowledge of the inputs and outputs of a system—a feel for situations and events that play out according to variables that the subject can control. A lack of or inadequate situational awareness has been identified as one of the key factors in accidents attributed to human error.[15]

PROPOSED RULEMAKING

BSEE was already considering relevant regulations with regard to RTM when the committee was asked to advise the agency on the use of RTM systems. Between the committee's first meeting in December 2014 and its Houston workshop on April 20–21, 2015, BSEE released two proposed

[15] In addition to the U.S. Coast Guard definition of situational awareness cited above, according to Endsley, situation awareness "is an understanding of the state of the environment (including relevant parameters of the system)." Such situation awareness "provides the primary basis for subsequent decision making and performance in the operation of complex, dynamic systems" (Endsley 1995, 65).

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rules. One, released February 24, 2015, concerned requirements for exploratory drilling on the Arctic OCS (*Federal Register* 2015b).[16] The second, released April 17, 2015, concerned blowout preventer (BOP) systems and well control (*Federal Register* 2015a).[17] Both proposed rules have RTM components as part of the new requirements:

- The proposed Arctic drilling rule includes an RTM component (see Appendix A) that would require companies to gather real-time data for the BOP control system and the fluid-handling systems on the rig, in addition to data on a well's downhole conditions during exploratory drilling operations, if downhole sensing equipment is installed. The Arctic rule would also require operators to transmit operations data to an onshore location, where the data would be stored and monitored by technically capable personnel who have the authority, in consultation with offshore personnel, to respond to an event or data abnormality (*Federal Register* 2015b, 9966).
- The proposed BOP and well control rule incorporates many industry standards and revises or reforms areas of well design, well control, casing, cementing, real-time well monitoring, and subsea containment. The RTM component in the proposed BOP rule (see Appendix B) states that within 3 years of the rule's final publication, well operations using a subsea BOP or surface BOP on a floating facility or operations in a high-pressure, high-temperature environment must "gather and monitor real-time well data using an independent, automatic, and continuous monitoring system capable of recording, storing, and transmitting all aspects of . . . (*a*) the BOP control system; (*b*) the well's fluid handling system on the MODU; and (*c*) the well's downhole conditions with the bottom hole assembly tools (if tools are installed)" (*Federal Register* 2015a, 21573). Furthermore, the operator must transmit the collected data immediately to a designated onshore location, where the data must be monitored by technically qualified staff who

[16] The new requirements for Arctic drilling are available at https://federalregister.gov/a/2015-03609.

[17] During the final stage of the National Academies report review process, BSEE released its final Blowout Preventer Systems and Well Control rule. In view of the timing of the release, the committee was unable to include additional information about the rule in its final report. The final rule is available at https://www.gpo.gov/fdsys/pkg/FR-2016-04-29/pdf/2016-08921.pdf.

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must maintain continuous contact with offshore personnel. When operations are completed, the operator "must preserve and store this data at a designated location for recordkeeping purposes," and both data and location must be accessible to BSEE on request (*Federal Register* 2015a, 21574).

With these proposed rules, BSEE appears to be preparing to incorporate RRTM into its regulatory framework. At the April 2015 workshop, some industry participants believed that the issuance of the proposed BOP and well control rule the previous week constrained their dialogue with the committee and BSEE. However, BSEE representatives were present throughout the workshop and engaged in the discussion. Ultimately, the committee does not believe that it was limited in the number and types of questions that it could pose to industry representatives. The committee recognizes that neither proposed rule has been finalized during the drafting of its report. On the basis of the information that it has gathered, the committee believes that the findings and recommendations presented in this final report provide BSEE with a basis for incorporating RRTM into its regulatory framework for the offshore oil and gas industry.

ORGANIZATION OF THIS REPORT

Chapter 2 provides a brief overview of offshore oil and gas operations, outlines some of the processes and data flow interactions between operators and contractors, and discusses industry experience with RRTM systems and their current application in drilling and production operations. Chapter 3 discusses potential benefits of and considerations concerning the use of RRTM in offshore drilling and production operations. It examines the potential use of real-time data and RTM in CBM. Regulatory considerations for BSEE are also discussed. Chapter 4 presents the committee's consensus findings and recommendations for the application of RTM of offshore oil and gas operations on the U.S. OCS.

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Abbreviations

BSEE	Bureau of Safety and Environmental Enforcement
DOI	U.S. Department of the Interior

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NAE	National Academy of Engineering
NRC	National Research Council
OIG	Office of Inspector General
TRB	Transportation Research Board

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2

Industry Overview

The organization and operation of the oil and gas industry are complex. Chapter 2 provides context for this study and for its findings and recommendations but not an all-encompassing review of the industry. It includes a brief overview of industry operations and background information explaining aspects of the offshore operational environment relevant to the application of remote real-time monitoring (RRTM). The chapter describes some of the basic processes that occur offshore and the interactions between operating companies and oil field service companies and contractors, as well as the interactions between this industry and the Bureau of Safety and Environmental Enforcement (BSEE). The basic RRTM environment and the flow of data between operators and contractors are explained, and the communications environment and relevant telecommunication technologies are illustrated. Finally, the chapter summarizes three recent studies on the topic of real-time monitoring (RTM) that are the focus of the committee's statement of task: the BSEE internal RTM report (BSEE 2014); the 838, Inc. report (838, Inc. 2014); and the committee's workshop summary (TRB 2015).

INDUSTRY PROCESSES AND INTERACTIONS

The federal government awards leases to oil and gas operating companies for extraction of resources from the subsurface under a sealed-bid auction process. The operating companies are responsible for the activities on their leases but do not carry out all of the activities by themselves. Drilling and oil and gas production operations involve complex processes, many companies, and highly trained and specialist staff from a wide array of technical and service disciplines. A multifaceted and dynamic

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industry supplies everything from specialist drilling and evaluation services to transportation and catering services, all of which are necessary throughout the exploration–production life cycle. That life cycle covers exploration for new oil and gas resources, the development of discoveries, the subsequent production of oil and gas and other resources, and the decommissioning and abandonment of depleted fields.

In the United States, BSEE is one of the federal agencies responsible for regulating the activities of this life cycle on the outer continental shelf (OCS). Its purposes are to promote safety and protect the environment. BSEE reviews required documents such as a company's application for a permit to drill new wells (APD), exploration plan (EP), and development plans for discoveries, and it performs on-site inspections of equipment, facilities, and processes. These actions allow the agency to oversee compliance with regulations and approved plans on a wide range of facilities and activities that include operations such as drilling, completion, workover, and production. In this section, the committee outlines these processes and interactions. The discussion is limited to the elements of the overall process that are relevant to this study on the application of RTM in offshore oil and gas operations.[1]

Drilling Operations

The operator generally holds the lease and contracts with other service providers for various aspects of drilling and operations. An overview of the major actors and processes is shown in Figure 2-1.

When wells are drilled by using a mobile offshore drilling unit (MODU), the operating company and leaseholder (key processes located in box with solid line) will do the preparatory technical work in support of the APD and EP. That work will include a complete assessment of the subsurface features to be drilled and a plan for drilling the proposed well safely. The assessment will include a number of uncertainties with significant effects on the design of the well and the planned operations. Through its representatives on the MODU and through the use of links to the operator's offices onshore, the operating company communicates

[1] For background information on and a more detailed description of offshore drilling operations, see Chief Counsel 2011 and NAE and NRC 2012.

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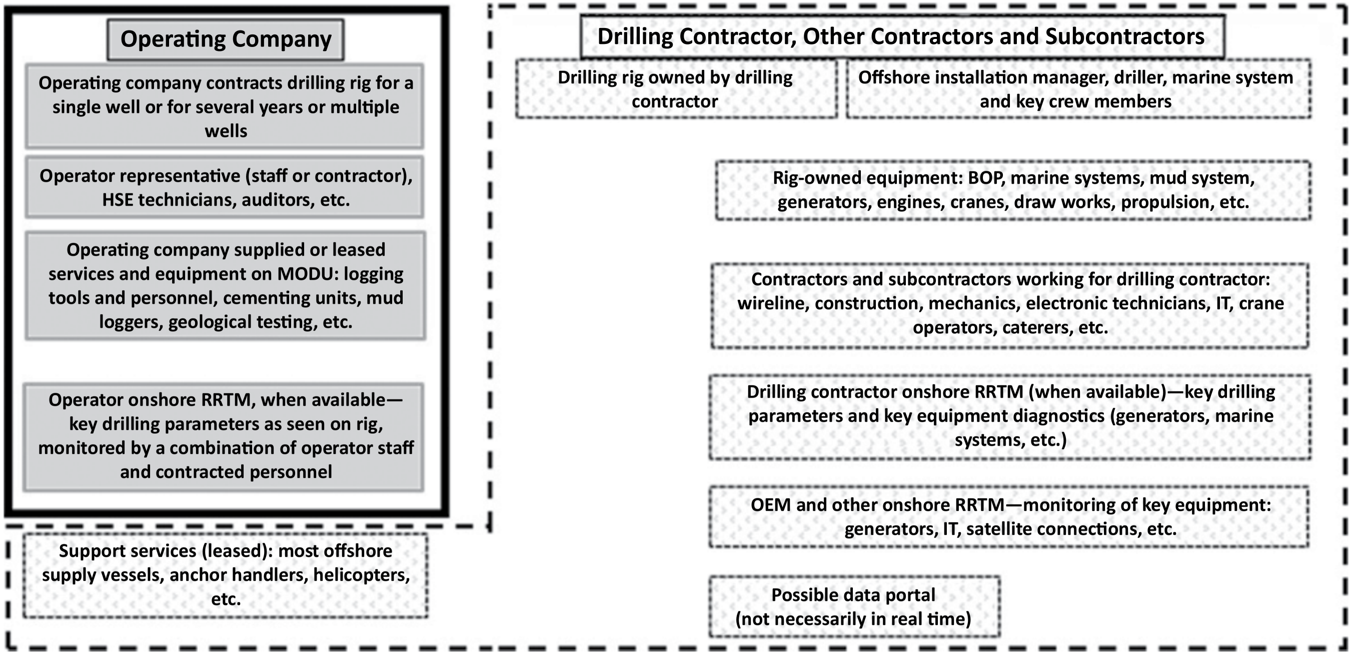

FIGURE 2-1 **Mobile offshore drilling unit** (MODU)**: key actors and processes.** The processes shown are those occurring during the drilling of a well that are particularly relevant to the discussion of RRTM (HSE = health, safety, and environmental; BOP = blowout preventer; IT = information technology; OEM = original equipment manufacturer; boxes with solid lines = operating company; boxes with dotted lines = contractors). (SOURCE: Generated by the committee.)

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with and directs the activities of many of the contractors during the drilling of a well. However, some specialized contractors and supporting-service companies will work directly for the drilling contractor, without the direct involvement of the operator. Key processes performed by the various contractors are shown within the dashed outline in Figure 2-1.

A MODU is owned by a drilling contractor, who leases the rig (including personnel) to an operator. The term of the lease can be as short as 1 to 3 months to drill one well, or it can be for a period of several years to drill multiple wells. Figure 2-1 also shows the involvement of other contractors (within dotted lines) during offshore operations, including specialist and technical services such as mud logging and wireline services; various services to operate and maintain mechanical systems on the MODU, such as cranes, pumps, electronic equipment, and generators; and transportation services and other support services such as catering. Depending on the nature of these contracted services, contracts will be in place with either the operating company or the drilling contractor.

During drilling operations, critical data are monitored on the rig by personnel charged with maintaining well control and making operational decisions in real time. In some circumstances, onshore specialists will be engaged to assist in the operational decision making, but the responsibility for those decisions ultimately rests with the staff on the MODU. Some MODUs have instrumentation and communication links to onshore offices of the operator and service company that allow for RRTM of the drilling operations.

BSEE, as well as the operator and the contractors, is involved during the planning and drilling process. The agency must approve required documents—for example, the APD and EP—and conduct regular inspections. Independent of joint ownership and contractual relationships, BSEE approvals and inspections will cover processes, such as the operator's safety and environmental management system (SEMS), and critical equipment involved in the drilling process. BSEE's general involvement with inspections is shown in Figure 2-2.[2]

[2] While other agencies such as the U.S. Coast Guard may have responsibility for inspecting some systems on board offshore facilities, BSEE is responsible for the inspection of the processes and equipment directly related to either drilling operations (on the MODU) or production operations (on the platform or facility).

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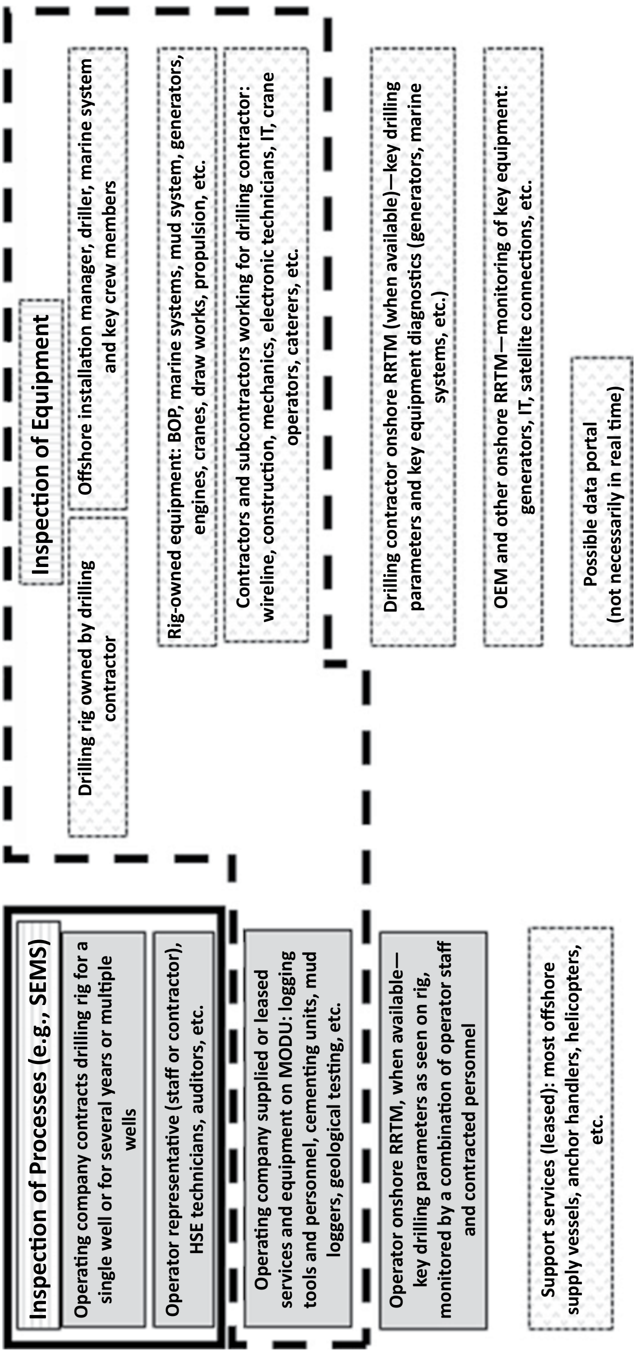

FIGURE 2-2 MODU: BSEE inspections during drilling process. The processes shown are those occurring during the drilling of a well that are particularly relevant to the discussion of RRTM (boxes with solid lines = operating company; boxes with dotted lines = contractors). (SOURCE: Generated by the committee.)

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As the name suggests, a MODU is mobile. MODUs perform drilling (and sometimes completion) services on a well and then move to the next location. In the case of a single well contract, the MODU's next well will be under a new contract with a different operating company and could involve a move to a different basin or area. Even in the case of a MODU under a long-term multiwell contract, a rig may move to a new location outside of the U.S. OCS to drill wells in the offshore waters of another country. Over their life span, most deepwater MODUs work internationally and make many moves between countries.

A number of factors can affect the ability of an operator or contractor to move MODUs globally in an efficient manner. One such factor is the changing communication environments between countries. Communications systems and capabilities differ between regions; in addition, countries have nonuniform laws concerning the sharing and transmission of data that could affect real-time data communications to and from remote locations. For example, requirements for data to be shared with a foreign government could result in a loss of confidentiality of technical information. In many jurisdictions, the transfer of data out of the country is illegal, which can severely limit the use of RRTM. Export control requirements on installed equipment could also complicate a MODU's move between countries.

Furthermore, a MODU's owner may have installed equipment required in one jurisdiction or requested by one operator. If the MODU moved to a jurisdiction where this equipment was not required under a new contract with a different operator, the new operator likely would not accept any increase in the day rate of the MODU associated with this equipment.

Many of the electronic and control systems are not standardized across the industry's MODU fleet. The fleet incorporates several generations of technical development over the past few decades. Furthermore, MODUs are custom-built, and operators coordinate with the contractor during the design and construction stages. The more modern MODUs are typically larger and have greater capabilities[3] for working in deeper water or in more complex subsurface environments, such as those with higher

[3] More detail about the various generations of MODUs and their individual capabilities can be found at http://petrowiki.org/PEH%3AOffshore_Drilling_Units#Rig_Types.2C_Designs_and_Capabilities.

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temperatures and pressures. Even in MODUs specifically used for deepwater drilling, significant variations in design, instrumentation, and capabilities can exist between different units and operators that make prescription of operational or communications protocols across a fleet difficult (TRB 2015).

Production Operations

Once a discovery has been appraised and determined to be commercial, a development plan is prepared by the operating company. This results in the installation of offshore production facilities to bring oil and gas to the surface. These facilities are referred to as platforms and typically are located above or near the producing field. The platform will be the host facility for producing wells, separation and initial processing of the oil and gas, treatment and injection or disposal of water, and export of the hydrocarbons. Export might be through pipeline; if the platform includes storage, export would be by tanker.

Increasingly, the offshore industry uses subsea development systems that allow the host platform to be dozens of miles from the producing wellheads on the seafloor, and a single platform can act as the host for a number of distinct fields spread over a large geographic area. Currently on the OCS, all subsea developments flow to a host platform located offshore. In this report, the offshore platform specifically refers to the host facility for a producing field, whether dedicated to a single field and located near it or located some distance away. In both cases, that platform exercises operational control over the field. Figure 2-3 shows the key actors and processes on a producing platform and the companies involved.

Production platforms are usually owned by the operator (outlined with the solid box in Figure 2-3). In most cases, the operator also owns the majority of the equipment installed on the platform, although some equipment such as compressors can be leased on a long-term basis. As in the case of a MODU, operating companies contract for the delivery of technical and support services. The contracted activities and processes (outlined with dashed lines in Figure 2-3) are necessary technical and support services for the operation of the platform. In some cases, floating production, storage, and offloading vessels are owned by a contractor and operated under a long-term lease to the operating company. In

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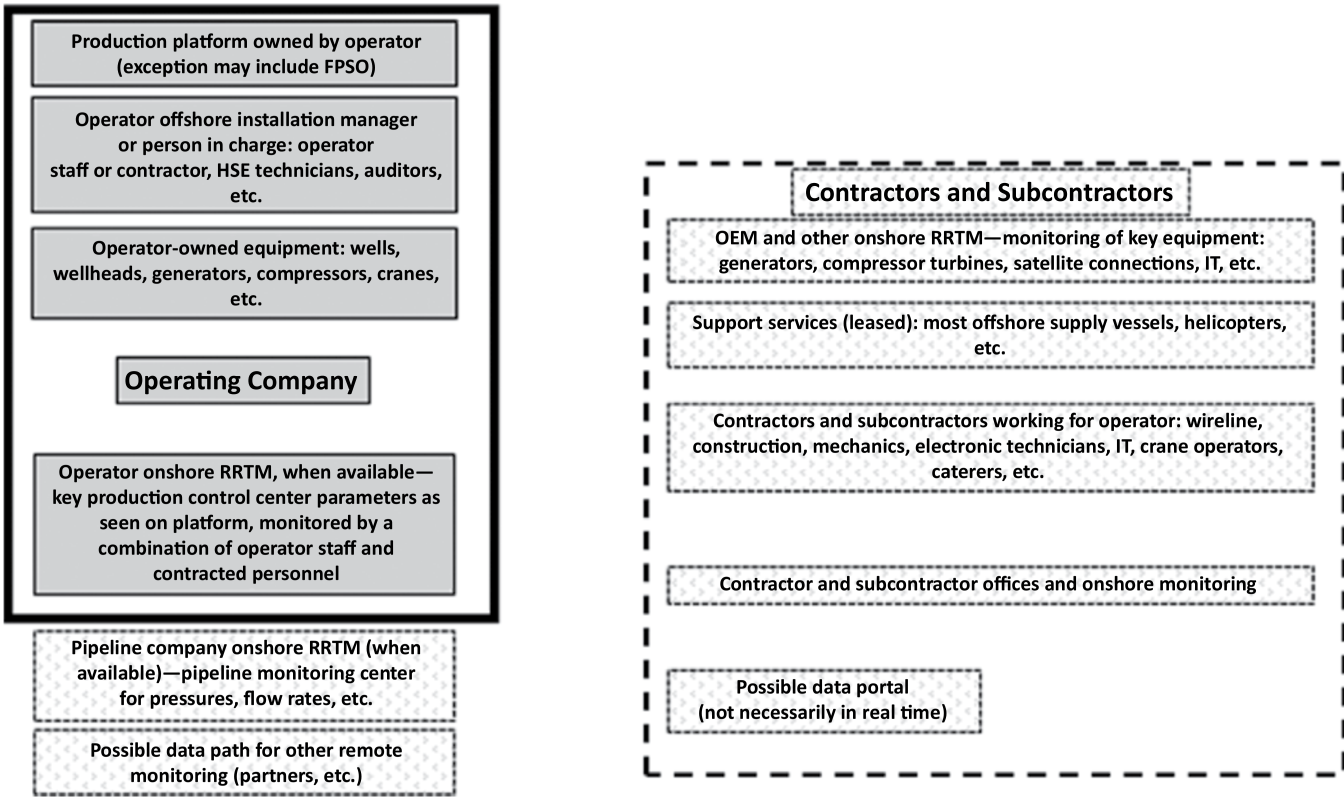

FIGURE 2-3 Production platform: key actors and processes. The processes shown are those occurring during production operations that are particularly relevant to the discussion of RRTM (FPSO = floating production, storage, and offloading; boxes with solid lines = operating company; boxes with dotted lines = contractors). (SOURCE: Generated by the committee.)

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such cases, the process owners might be different from those shown in Figure 2-3; however, the operating company retains the responsibility for all activities on the lease. The operator is usually responsible for the communication and information technology, connectivity, and monitoring systems on the platform, although a high degree of integration with systems utilized by contractors or service companies for monitoring their equipment or processes may be required.

As the regulator, BSEE is involved in the production process through the approval of various documents such as the development plan and through required regular inspections of the production platform. As in the case of MODUs, BSEE inspections (see Figure 2-4) cover processes (shown in the solid-lined box) such as the operator's SEMS and include equipment that may be owned and operated by the operator or various contractors, as indicated by the boxes with dashed lines in Figure 2-4.[4]

Drilling rigs are installed on some production platforms for purposes of development drilling and redevelopment. An installed drilling rig will be physically placed on the deck of the production facility. In these cases, the processes and relationships shown and described above for MODUs are largely embedded with those on the production platform. The operator contracts with a drilling contractor and other service providers, usually on a long-term basis, for the necessary services for drilling wells. Contracts will be in place to support this work, and BSEE will inspect equipment and processes.

As in the case of MODUs, many electronic and control systems on platforms are not standardized across the industry's production operations. Platforms producing in the OCS represent many generations of oil and gas development as well as generations of development of embedded systems such as controls, electronics, and communications. Over the years, facility design, the design of subsystems, and levels of instrumentation and automation are often upgraded to varying extents among operators and contractors. The first fixed production platforms were installed in deep water in the 1970s and the first floating platforms in the

[4] While other agencies such as the U.S. Coast Guard may have responsibility for inspecting some systems on board offshore facilities, BSEE is responsible for the inspection of the processes and equipment directly related to either drilling operations (on the MODU) or production operations (on the platform or facility).

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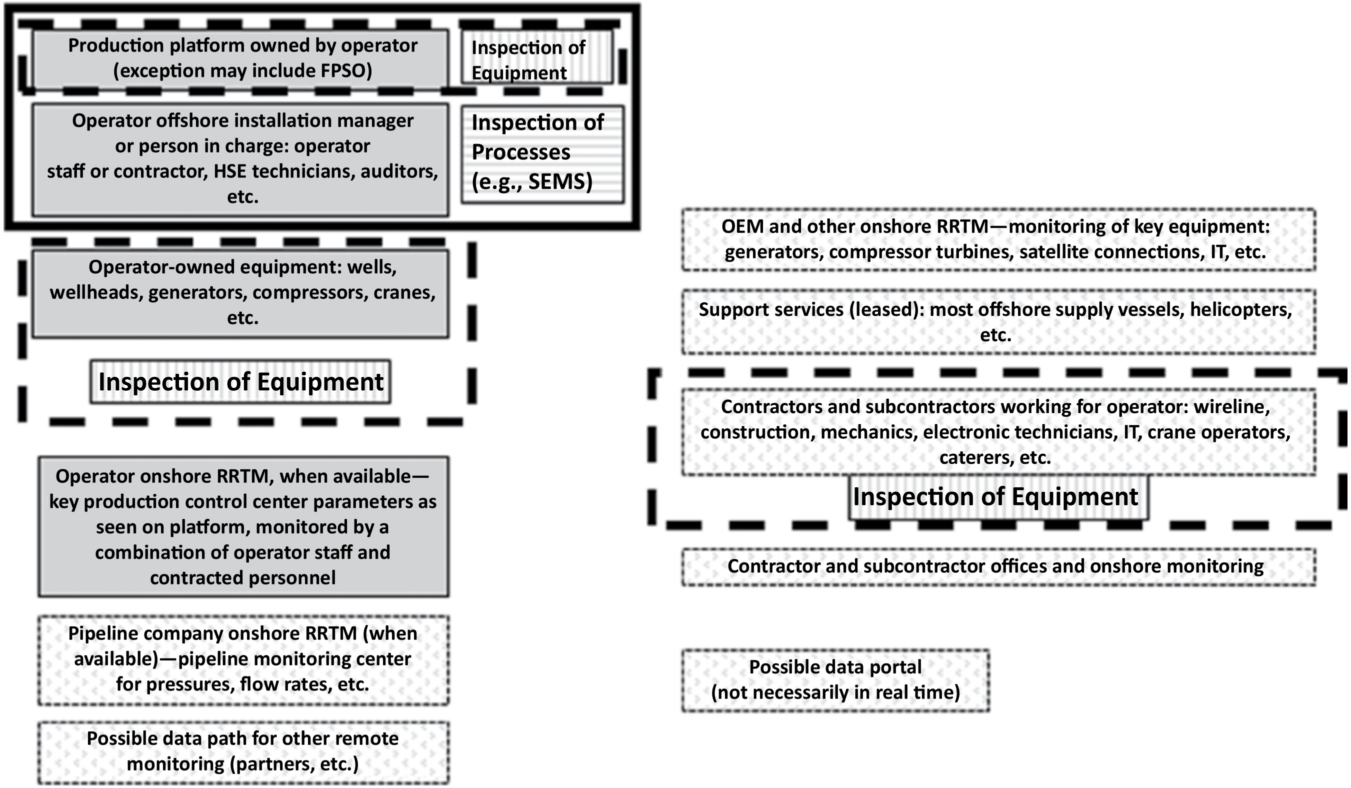

FIGURE 2-4 Production platform: BSEE inspections during production operations. The processes shown are those occurring during production operations that are particularly relevant to the discussion of RRTM (boxes with solid lines = operating company; boxes with dotted lines = contractors). (SOURCE: Generated by the committee.)

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1980s. Some upgrades have taken place, but as the committee heard at its workshop, many offshore facilities and legacy systems have not been or cannot be upgraded (TRB 2015).

RRTM in Drilling Operations

The use of RRTM is highly variable across the industry. As mentioned in Chapter 1, regardless of the method of implementation, the industry's business case for establishing RRTM centers to monitor drilling operations has been focused on improving efficiencies and enhancing risk management through better operational planning and execution (Laurens and Kales 2014). Some companies have been using the technology continuously for many years; others have not adopted it at all.

Over the past few years, more offshore operators have implemented RRTM systems on MODUs, and industry experience is growing rapidly. Service companies can provide links to data from their systems so that operators can access those data from remote (onshore) locations, and in some cases these data are integrated with other operational data that the operator monitors.

The operators and service companies use different models for remote onshore monitoring centers. Some companies, such as BP, Chevron, and Shell, have centers that function 24 hours a day, 7 days a week (24/7) and are staffed by technicians with offshore experience who each monitor two or three active wells. Other operators may only staff their RRTM center during weekday business hours, with each technician monitoring one to four wells. In these cases, the center is available 24/7, if necessary, during critical operations or at decision points. Onshore personnel also can access data from other locations (such as their desktops or homes) via laptop computer (TRB 2015).

Service companies, such as Halliburton and Schlumberger, maintain 24/7 RRTM centers to provide specialized services to operators as well as to monitor the efficiency of their own equipment installed on the MODU. The operating company's drilling engineer or superintendent typically has software access to the service company's data and can access data by computer from outside the RRTM center.

During drilling operations, the wellsite personnel have full responsibility and accountability for decision making. The remote monitoring centers

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focus on abnormal trends or well events; provide additional support for the MODU; and offer advice, support, and improved access to onshore technical expertise. RRTM enables collaboration with engineers, geologists, technical specialists, and other onshore staff without their having to fly to the offshore facility, which would be time-consuming, would cause delays in decision making, and would increase the overall risk in offshore operations. In addition, remote centers can check incoming information streams for valid and reliable data, which allows for development of a knowledge base and for data analysis. In general, panelists at the committee's first meeting indicated that RRTM can reduce nonproductive time and improve safety on the MODU and that RRTM is a support tool allowing an operator to manage its operations efficiently and effectively.[5]

The situational awareness gained from being on the offshore facility is critical. The belief that operational decision making belongs offshore is based on decades of direct experience and is broadly held within the U.S. oil and gas industry. Even when a remote center is available, there is no expectation that the offshore staff will check with the remote center or ask permission before making decisions. Thus, explicit protocols must govern any interactions between offshore operating staff and the remote center. Across the industry, operators use different protocols. Because operating systems, contractual arrangements, rig instrumentation, and communication technologies differ so widely, standardization between companies does not exist, and establishing one consistent protocol would be difficult. The design of communication protocols in the operation of RRTM centers has been carefully thought out by the operating companies, and each company documents its protocols and follows them when issues arise.

Figure 2-5 shows data flows that are typical during drilling on a MODU and shows how data move between contractors and operator to a remote real-time center. While the data flows are independent of the contractual relationships, the contracts must recognize the presence of a remote monitoring center, if one exists, and the capabilities of the critical MODU

[5] See presentations from B. Gaston, Shell; C. Harder, BP; and G. Buck, Chevron, at the committee's December 5, 2014, meeting (http://www.trb.org/PolicyStudies/CommitteeMeetings1.aspx).

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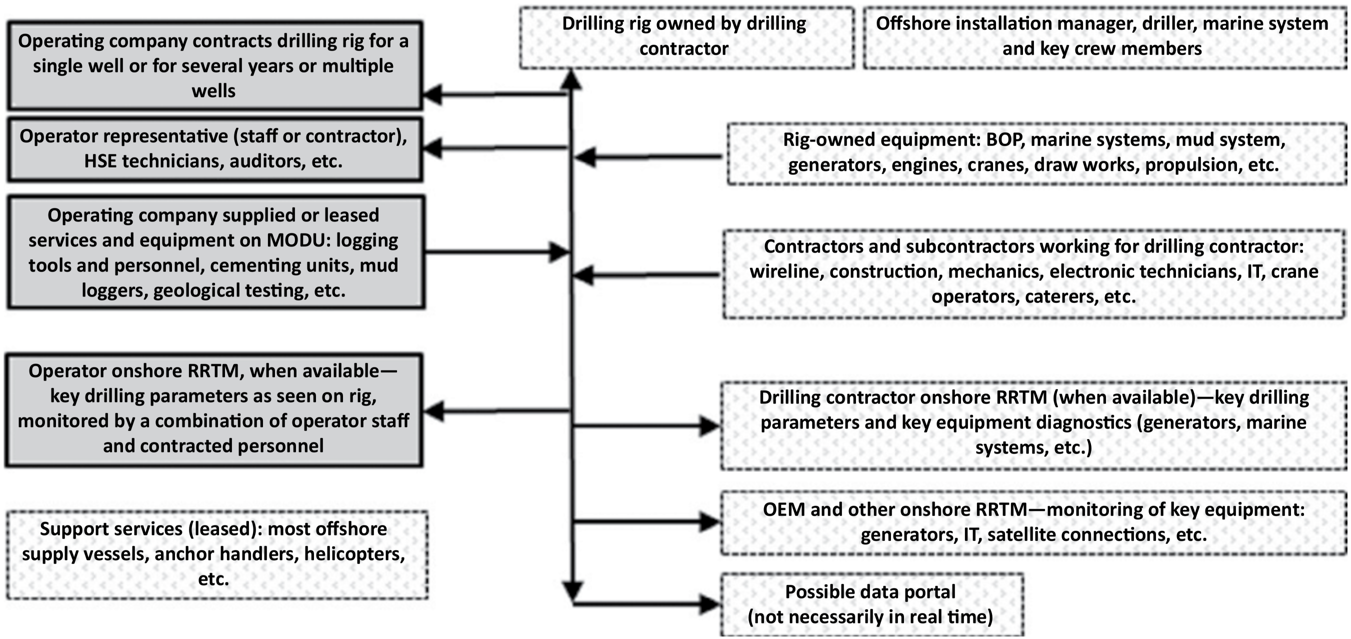

FIGURE 2-5 **MODU: Sample data flows between operator and contractors.** The processes shown are those occurring during the drilling of a well that are particularly relevant to the discussion of RRTM (boxes with solid lines = operating company; boxes with dotted lines = contractors). (SOURCE: Generated by the committee.)

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systems and how the systems are instrumented. The fact that the drilling contractor does not necessarily own all of the equipment on the MODU is important. Critical systems that typically would provide data to an operator's remote real-time center, such as the drilling mud system and logging tools, are often owned by subcontractors. The systems are monitored on the MODU through custom interfaces and connections, and they must be compatible with any electronics or other systems installed on the MODU to enable remote monitoring. When the operator does not have a remote monitoring center, contractors may need to supply remote data links for geologic or operational data, which complicates the contractual arrangements and data flows. In addition, different activities, such as mud logging, wireline logging, measurement while drilling, and monitoring of rig equipment, are handled by different skilled personnel on the MODU. A remote center could be set up and run by the operating company or could be offered by a contractor as part of its specialized services, which further complicates the planning and implementation of RRTM for drilling.

RRTM in Production Operations

Several operating and service companies use RRTM for drilling operations, but the use of RRTM to monitor offshore production operations is more limited. The committee is only aware of a few platforms, operated by Shell and Chevron, where RRTM centers have 24/7 monitoring and ongoing support and collaboration for production operations. In considering the use of RRTM for production monitoring, the important differences between the production and drilling environments must be recognized.

The complex systems and data flows of MODUs differ from those of production platforms. Different parties monitor different parameters and systems, and the information flows and communications links vary with the type of data. In addition, MODUs typically have short- to medium-term contractual arrangements (a few months to a few years), while production platforms have longer-term arrangements of many years to decades. Over the life of a production platform, the risk level can change dramatically. Declines in produced volumes of oil and gas, declining pressures, changing fluid composition, the presence of drilling or redevelopment activities, and many other changes will independently

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increase or decrease the risks associated with operations. In addition, a producing asset may be sold to a different (often smaller) operating company. The design of RRTM for production monitoring must consider these factors, which are unique to the producing environment.

Figure 2-6 illustrates the data flows typical during production operations. It is similar to Figure 2-3, which shows the key processes and relationships for production facilities. Across the production process, there are complex systems where operational and data responsibilities are partitioned between the operator and many contractors. Different platform systems are the products of many original equipment manufacturers and vendors and can operate on software systems that are often not compatible. Data flow between numerous parties for RTM of production operations. The design and operation of the monitoring center need to manage all of these challenges over the life of the platform.

The operation of remote monitoring centers for drilling and production operations is often undertaken to increase efficiency and enhance operational safety. Different centers serve different purposes, and their operation reflects this. Some operators are committed to RRTM 24/7 for both drilling and some production; others operate remote monitoring centers only for drilling and normally staff them only during weekdays. Some operators do not believe that RRTM provides a significant advantage and have not integrated the practice into their offshore operations. The wide variability of implementation is a significant aspect of current industry experience with RRTM.

Communications Environment for OCS Oil and Gas Activities

Decades ago, communications between offshore production facilities and onshore support centers were often limited to two-way radios and daily reports. The staff on each offshore facility made decisions on the basis of information generated and collected at the rig. The technology of offshore communications has advanced over the years and allows the transfer of real-time data for improved interactions between offshore and onshore operations. Still, situational awareness on the offshore facility is important, and the U.S. offshore industry believes that the responsibility for decision making ought to remain offshore, even

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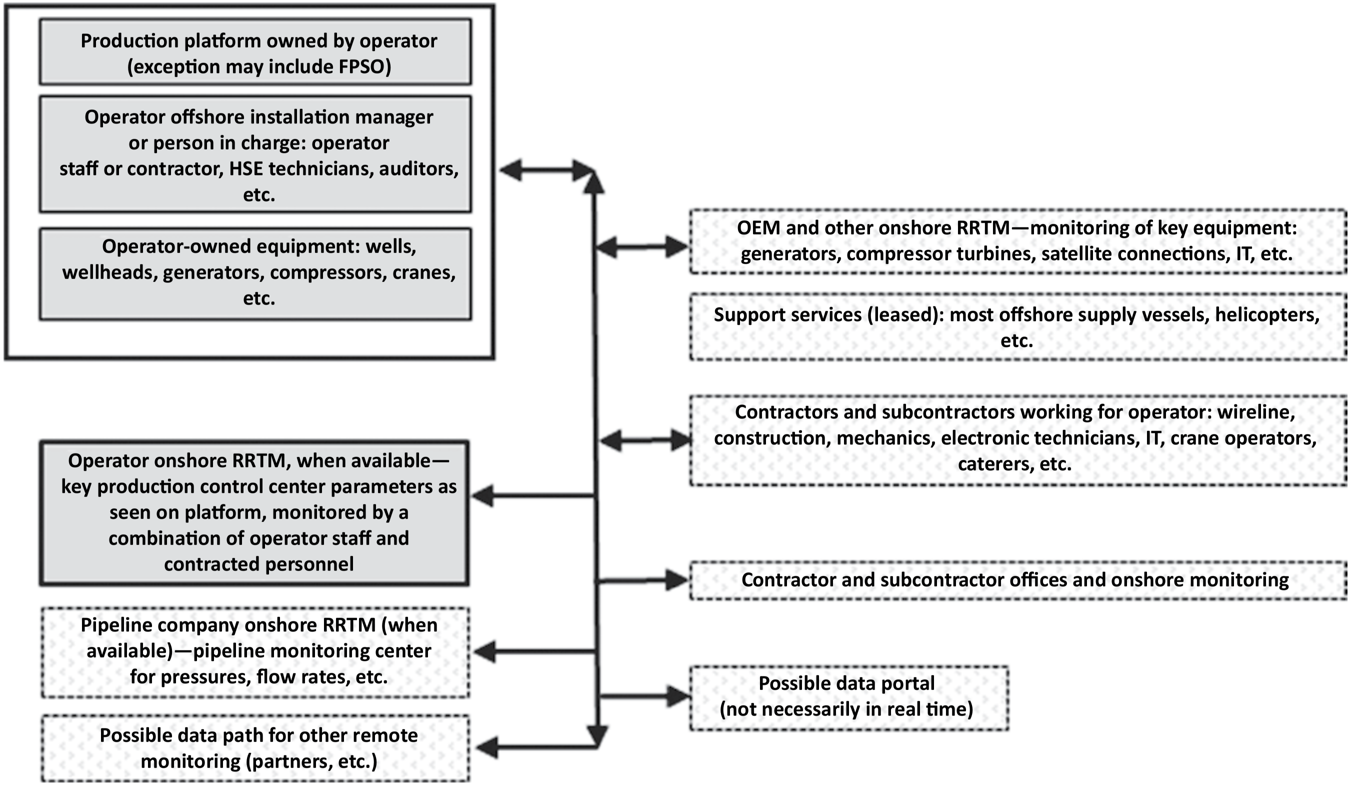

FIGURE 2-6 Production platform: sample data flows between operator and contractors. The processes shown are those occurring during production operations that are particularly relevant to the discussion of RRTM (boxes with solid lines = operating company; boxes with dotted lines = contractors). (SOURCE: Generated by the committee.)

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with the real-time transfer of offshore data to onshore offices for decision support and troubleshooting.

The determinants of which technologies are used for offshore communications include the distance involved, the remoteness of the installation, the amount of data that must be transmitted, the availability of the technology, and the cost of the provided services. Among the communications technologies are satellite, microwave, fiber optics, and cellular services. Implementation barriers among these technological alternatives can include issues such as bandwidth, latency, reliability, performance, and affordability (see Appendix C). Any solution will involve a system engineering approach considering all components of the communications environment. A simple illustration of this offshore oil and gas environment is shown in Figure 2-7.

Satellite technology, available in most areas around the world, is a widely chosen solution for offshore communications and includes three main components: a very small aperture terminal at the offshore site, an orbiting satellite, and a receiving center located onshore. Microwave technology can offer extra bandwidth for data and is often used for shorter distances, especially for facilities that are near each other. Fiber technology is also a good solution for grouped facilities, but cables must be installed between facilities, which can be expensive. Cellular service can be accessible at some locations offshore. A comparison of the attributes for each common communications solution is shown in Appendix D. Integrated solutions for offshore facilities can include satellite communications to a main facility and microwave or fiber between offshore wells or facilities. Communications technologies can be integrated into each offshore facility, allowing the transfer of real-time data from subsea wells to multiple facilities.

Automation and Predictive Software

Automation, in the context of RTM, is taken to mean computer algorithms that utilize offshore data to provide displayable alerts or other computations for human interaction or that are used in a feedback mechanism to control offshore equipment. Automation can occur at an offshore facility or at an onshore remote monitoring center. It can be as simple as displaying an alert status when a data parameter exceeds preset limits or as complex as computing expected pit volume during tripping as an

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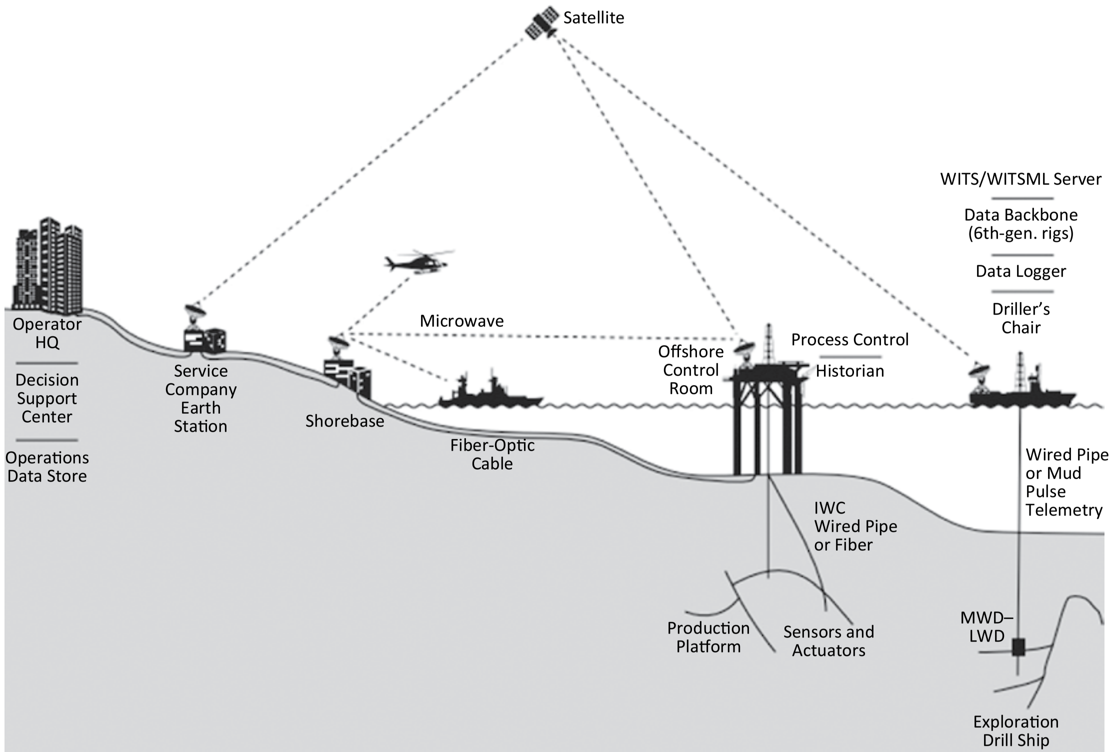

FIGURE 2-7 Offshore RTM environment: simple layout of offshore information and communication technology infrastructure (WITS = Wellsite Information Transfer Specification; WITSML = Wellsite Information Transfer Standard Markup Language; gen. = generation; HQ = headquarters; IWC = intelligent well completion; MWD = measurement while drilling; LWD = logging while drilling). (SOURCE: Generated by the committee.)

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indication of a well control abnormality. The deployment of automation in offshore drilling and production facilities is limited to a few select processes, such as handling drill pipe during the drilling process. Automation opportunities exist where processes (or interactions) are known, where constant performance to known standards is desired, and where human decision making or analysis is not required. At the April 2015 workshop, service company representatives indicated that they use automation in some processes such as automating alarms and data gathering to improve data quality—and potentially workflows and decision making—and to set and maintain the desired well path and heading with rotary steerable tools (TRB 2015, 31). In addition, no offshore MODU has any process that is automated and controlled from onshore (TRB 2015, 37).

The application of predictive software depends on the degree of uncertainty and complexity of a system, as does automation. Predictive software can be based on either fundamental physics-based models or a statistics-based algorithm, where a high degree of correlation between inputs and outputs can be represented by a statistical method, such as neural networks, machine learning, or artificial intelligence. Research on predictive software has been conducted in many areas of oil and gas exploration and production, but it appears to have met with more success in the area of equipment health and predictive maintenance. As stated during the April 2015 workshop, drilling operations are not like factory operations and are not done in a controlled environment. Instead, they rely on estimated parameters within a range of assumed values. These types of operating conditions highlight the difficulty of building accurate predictive models on which to base automated actions. Some predictive software can be used for processes such as connection-flow monitoring and a heat check calculator for casing wear, but these uses only supplement what is done on the rig; they do not replace it (TRB 2015, 24).

SUMMARY POINTS ABOUT RTM FROM PREVIOUS REPORTS

The following subsections briefly review the main themes and topics of three reports. The first report, by an internal BSEE workgroup, reviews the potential uses of RTM technologies for both the government and

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the oil and gas industry. The second report is by 838, Inc. That report provides background material on RTM and available technologies. The third report is the workshop summary authored by the committee.

BSEE Internal Report

To learn more about RTM technologies and best practices, BSEE conducted site visits to RTM centers during summer 2012 and then established an internal RTM team in fall 2012 to develop preliminary findings on how the oil and gas industry and BSEE could benefit from the use of RTM technologies. After more than 1 year of work, the BSEE RTM team produced a final summary report detailing its findings and recommendations (see BSEE 2014). The BSEE team focused on two areas:

- Use of RTM by industry: What minimum requirements should BSEE establish in its regulations for the use of RTM technologies by the offshore oil and gas industry?
- Use of RTM by BSEE: How should BSEE use RTM technologies to carry out its safety and environmental protection responsibilities more efficiently and effectively?

To structure its investigation, the BSEE team formed three subgroups corresponding to the general categories of offshore activities: drilling operations, completion and workover operations, and production operations. Each subgroup was given the task of identifying critical operations and parameters for its activity that should be monitored by using RTM technologies.

The breadth and details of the results of the study vary across the two areas of interest and the three types of operations. For example, for industry use of RRTM, the report recommends capturing and monitoring more than 50 data streams for drilling and completion and workover operations (e.g., monitor both primary and secondary BSEE-approved pressure settings, including pump pressure settings and fluid low-level alarms).[6] For production operations, only three simple measures are

[6] For a complete list of suggested operations and parameters, see BSEE 2014 (Annex 1, p. 14; Annex 2, p. 17; and Annex 3, p. 20).

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suggested [e.g., the total number of safe chart safety devices currently bypassed (see BSEE 2014, 21)]. According to the report, three attributes are critical for an effective RRTM center:

- A center must receive data from offshore sites allowing companies to provide a network of experts and to offer advice and troubleshoot issues from onshore.
- Constant communication between offshore sites and the onshore center is vital if onshore personnel are to maintain awareness of offshore operations. Effective communication between offshore and onshore staff demands clear protocols and procedures on how to identify, verify, and escalate safety concerns, and guidance should be provided on who should talk with whom.
- A center must have experienced and highly trained personnel, who must gain the trust of offshore personnel.

Many of the recommended data streams are already recognized and regularly captured by industry operations with RRTM capabilities.

Since RRTM information is not being used by the agency, the BSEE report takes a different tack in discussing BSEE's use of RRTM and explores possible opportunities by delineating the following:

- The potential of RRTM for BSEE responsibilities through a risk-based inspection strategy that supplements (and fundamentally changes) its current program.
- The critical RRTM-relevant operations and data streams from drilling, completion, workover, and production activities—the identification of operations and data streams will need to occur before any role for BSEE or requirements for industry are discussed.
- The role for BSEE personnel in overseeing critical drilling, completion, and workover operations with RRTM. To prevent their being a distracting presence, any new or active oversight role by BSEE would require personnel with the proper qualifications, training, and experience. Legal implications and understanding of the safety issues and risk factors for each well operation are additional considerations of such an oversight role.
- The importance of direct communication between BSEE and the facility's offshore control room. The BSEE report acknowledges that

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such a communication link could lead to BSEE personnel becoming a distraction during operations.

- The unknown technological and legal challenges that obtaining RTM data from multiple operators poses. Industry RRTM operations are not standardized and use various systems and data formats. Resolution of compatibility and technical issues, such as connectivity, bandwidth, and cost, as well as legal issues of collecting, storing, and protecting proprietary information, is important.
- The usefulness of existing reports [e.g., daily drilling reports from the International Association of Drilling Contractors (IADC)]. Although BSEE already requires operators to submit Form BSEE-0133, IADC's daily drilling report would provide more detailed drilling information.

The BSEE report discussion gives rise to a range of opportunities and scenarios for incorporating RRTM into BSEE's safety program. Some options, such as gaining access to existing IADC reports or traveling to an operator's remote monitoring center, are easier to adopt; others, such as establishing a BSEE RTM center for offshore operations, are more difficult for technical, legal, operational, and cultural reasons.

838, Inc., Report

To provide additional background on available technologies, BSEE commissioned an external report (see 838, Inc. 2014) titled *An Assessment of the Various Types of Real-Time Data Monitoring Systems Available for Offshore Oil and Gas Operations.* This subsection briefly summarizes some of the main topics from the more than 200-page report. The authors addressed seven main tasks:

1. **Discuss the current state of RTM.**[7] Within the current state of RTM, the authors found five basic uses for real-time data technologies:
   - Subsurface and formation analysis and well planning and modeling tools;
   - Wellbore stability and drilling integrity (downhole) monitoring and analysis;

[7] See 838, Inc. 2014, pp. 21–36, for a list of existing technologies.

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- Instrumentation for drill floor and rig operations;
- Bandwidth availability and standardized languages for data collection and transmission; and
- Onshore center—data aggregation standardized interfaces, screens, display of relevant data, user interface, predictive capabilities, and monitoring and alarming potential.

2. **Perform a cost–benefit analysis of RTM.** The authors indicated that the results of any cost–benefit analysis for RTM will depend on the size of the company, but they emphasized that their report's cost–benefit analysis is only for illustrative purposes. Even on the basis of conservative estimates, the authors conclude that the use of RTM centers is justified and can increase efficiency and elevate safety.
3. **Discuss the relevant training needed to conduct RTM.** To conduct RTM, relevant training will be needed. However, before any effective training program can be developed, the authors believe that BSEE needs to define the proposed oversight system clearly. After discussion of safety oversight and system safety models, the authors propose three training scenarios for incorporating RTM into BSEE processes: (*a*) BSEE personnel would complete a focused internship with an operator; (*b*) BSEE, along with industry, would develop curriculum and training courses to improve understanding of RTM technologies; and (*c*) BSEE would develop a simulation center, modeled after an industry RTM center, to train personnel in best practices through use of actual (deidentified) data; the center would be established and maintained in-house.
4. **Identify the critical operations and parameters to be monitored with RTM.** Drilling operations produce multiple data flows with large volumes of data, especially on the newer generation of MODUs. The authors discuss collected, monitored, and calculated information for well operating conditions and note that modeling and modeling technology, along with real-time data, offer great benefits to offshore operations, from planning a well to postdrilling analysis.[8] The authors conclude that modeling before starting to drill provides

[8] See 838, Inc. 2014, Chapter 4, pp. 110–124, for a list of data collected and monitored; types of calculated data are listed on p. 123.

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greater insight into the process and that using simulation programs incorporating real-time data during drilling operations can increase efficiency and promote safety. Furthermore, training simulators that use postprocessed data can enhance the experience of personnel by improving situational awareness and procedural understanding.

5. **Discuss how RTM can be used for condition-based monitoring.** The authors survey and describe sensor technologies used by industry to measure and report performance and to predict failure of monitored equipment. The report discusses the digital oil field and the importance of collecting, managing, and analyzing data. Reliable and valid data are the basis for all analysis and decision making. Advances in sensor technology have allowed industry to increase the amount and improve the quality of collected data from critical systems, leading to more efficient and reliable equipment. Only a subset of the total available data are recorded. Industry will need better methods of data storage, transmission, and analysis as more data are collected and managed.
6. **Discuss how RTM can be incorporated into BSEE's regulations.** The authors believe that incorporating RTM requirements into the BSEE regulatory regime could have great benefits for industry, including promotion of safe and efficient exploration, extraction, and production of hydrocarbons. However, BSEE would need to incorporate the principles of system safety. To enhance safe operations, the authors suggest that BSEE implement a voluntary safety reporting system and the sharing of industrywide data among operators.
7. **Discuss how automation can enhance RTM.** The authors assess the principles of automation and automation currently available in the oil and gas industry. Although automation has human health and safety benefits, such as limiting exposure to dangerous environments, several challenges are associated with its use. Among them are the need for preventive maintenance, reliance on timely and high-quality data, and complacency. Overall, the authors note that automation in the upstream oil and gas industry is in its initial stages.

The authors conclude that the use of RTM centers is viable and that new regulations on the use of RTM should include onshore monitoring of well parameters by a separate safety center. However, the new

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regulations should be introduced gradually, starting with the drilling of high-risk wells.

Common Themes and Observations from Committee's Workshop Summary Report

As a central part of its remit (see Box 1-1), the committee conducted a workshop on the application and use of RTM systems by industry and government. The workshop focused on the Gulf of Mexico region and addressed the five issues listed in the statement of task. In preparation for the workshop, the committee provided each of the panelists a copy of the two reports (described above) and a standard set of questions to address (see TRB 2015, Appendix B). The presenters were not limited to these questions, but the committee wanted to ensure that, at a minimum, specific issues relevant to the statement of task were addressed. The following summary observations and statements are from industry panelists who participated in the committee's April 20–21, 2015, workshop in Houston, Texas.

Drilling Operations

Drilling operators were represented by the following companies: Total E&P USA, Shell, LLOG Exploration, Noble Energy, BHP Billiton, and Murphy Oil Corporation. RRTM is not currently required on all wells of most of the panelists. Whether a well should be monitored (offshore or onshore) is determined by a business case and based on risk. Many companies can stream data onshore to monitor wells on a continual (as-needed) basis, but they do not necessarily monitor the well data 24/7. The panelists emphasized that RRTM is one of several tools supporting operations on the rig and providing another set of eyes, but that it does not take over the operational decision making on the MODU. Furthermore, without full situational awareness of what is occurring on the MODU, real-time data are not entirely useful. The panelists suggested that RTM can be valuable in terms of efficiency and can save money in well planning and well execution, and it can help identify equipment that is out of calibration or can assist in incident investigations. As mentioned above, automation and predictive software are less advanced than other RTM software and applications, but predictive software might be used

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to determine baseline trends and to flag any deviations. Some panelists believed that industry as a whole could improve how data are collected, integrated, and stored.

Some panelists suggested that blowout preventer (BOP) systems could be monitored remotely—if they are updated properly—since they are mechanical and relatively static and their operation is not reliant on downhole systems. The panelists insisted that remote monitoring of BOP pressure tests should not replace BSEE's on-site inspection programs but could supplement its on-site compliance enforcement with remote tests once the tests were shown to be reliable. Panelists suggested that BSEE could use archived data to understand issues, verify information on daily drilling reports from IADC, or help in incident investigations.

The panelists suggested that any new RTM regulation be performance-based but not require a fixed structure or building. The operator should be allowed to show how the data will be accessed and used on a real-time and postevent basis. While RRTM can lead to better team integration and better data quality, the panelists suggested that the benefits of RRTM to health, safety, and environment are difficult to quantify.

Third-Party RTM Providers

These panelists included representatives from Baker Hughes, Schlumberger, Halliburton, Weatherford, Petrolink, and Genesis Real-Time Systems. Third-party providers generally use RTM of critical operations to reduce nonproductive downtime and to optimize performance, but RTM can also help manage costs and avoid hazards. The panelists emphasized that data generated from the MODU belong to the operator. They advised that RTM data could supplement decision support for field operations through the use of alarms and alerts, knowledge management, and data interpretation, as well as through predictive and preventive maintenance of safety equipment. Several panelists said that condition-based monitoring is used to track the health and performance of some critical equipment, which helps with preventive maintenance.

The panelists emphasized that the responsibility for offshore operations should remain with the MODU and well personnel and that operational decision making and accountability should continue to

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reside with the operator. Although remote centers can complement operations on the MODU, the panelists reminded the workshop participants that there is no big red button in the remote center to shut everything down.

Industry uses a wide range of RTM technologies, and the panelists believe that a standard approach will not work for everyone—one size does not fit all. Each operator has its own data requirements when it interfaces with contractors, and although standards exist, they are not always followed. Still, if an RRTM center will be asked to provide the same level of insight as on the MODU, the panelists suggest that all MODU data should be transmitted to the remote center. Redundancy is important for many of the critical sensors on the MODU. As more data are collected and transmitted, panelists noted, cybersecurity issues and the use of mobile devices to display that information will create additional risk to cloud-based services.

Schlumberger shared five key lessons that the company has learned from running an RTM center: developing companywide standards, formalizing workflow, understanding personnel, establishing communication protocols, and using appropriate advanced monitoring tools.

Production Operations

Chevron, Marathon Oil, Stone Energy, Anadarko, and Shell presented for this panel. Production operations are largely steady state in nature, and RTM for production is driven by business need—primarily for production optimization, efficiency, and reliability. The panelists agreed that all command and control should occur at the offshore facility. Generally, production facilities are not monitored or staffed 24/7, with maintenance activities often limited to daytime hours. RTM is primarily used for diagnosing and troubleshooting equipment to limit downtime. Accordingly, RRTM for production facilities is not viewed as a safeguard for personal or process safety. Whereas RTM and condition-based maintenance allow intervention with critical equipment before a failure occurs, this intervention often uses archived rather than real-time data. This process allows the operator to capture and analyze data, produce trends, and make decisions, but not instantaneously.

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Drilling Contractors and Equipment Manufacturers

The companies presenting at the workshop included Diamond Offshore Drilling, Transocean Offshore Deepwater Drilling, Pacific Drilling, CAD Control Systems, and the Athens Group. Drilling contractors are contracted by the operators to perform operations and typically collect and provide all data to the operator. The types of data are usually specified in the contract. While contractors remotely monitor equipment to perform preventive maintenance, those data are not monitored in real time. The collected data are usually archived and analyzed later. In addition, not every MODU can transfer data onshore in real time. The panelists suggest that any attempt to leverage RRTM technologies be prototyped before being fully implemented.

Cybersecurity is becoming a larger issue for some critical MODU equipment. Industrial control and automation systems are designed to work in harsh environments over long periods. Most of these control systems are thoroughly tested and not touched again. However, remote connectivity and security, which were not part of the original system design, could add risks to the system.

According to the panelists, technology allowing RRTM of the BOP control systems is available, but it is not being used fully. The available data include information such as hydraulic pressures, opening and closing pressures, and volumes, but not the actual positions of the BOP rams. BOP health can be monitored with current technology, but mainly to determine the remaining life of the BOP. BOP health is not monitored in real time or 24/7. Drilling contractors mainly want to optimize maintenance practices. The panelists suggest that BSEE inspectors could have access to reports on BOP test results and equipment condition before inspections.

Trade Associations

This panel consisted of representatives from the American Petroleum Institute, the Offshore Operators Committee, IADC, and the National Ocean Industries Association. The panelists emphasized that shore-based personnel use RRTM as a support tool to improve the efficiency of certain wellsite operations, which may also favorably affect safety and the environment. In addition, RTM is only one of many tools used by industry to support safe operations. They indicated that RTM requirements for drilling operations differ from those for production operations.

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According to the panelists, the proposed BOP rule (mentioned in Chapter 1) could introduce uncertainty into the chain of command, have significant impacts on smaller operators, and change competitiveness in the Gulf of Mexico. The objectives and desired benefits of RTM, in the opinions of the panelists, need better clarification and a defined problem statement from BSEE before consensus-based industry standards can be developed. Clarity of purpose is key for this development. The panelists also suggest that BSEE clarify how the proposed BOP rule would interact with existing regulations concerning obligations and liabilities of the contractors performing the activities. Finally, as technology advances, RTM will evolve. If requirements or regulations are to remain relevant, the panelists recommend that BSEE consider performance-based rules.

SUMMARY DISCUSSION

This chapter describes the processes and relationships in offshore oil and gas exploration and production as they relate to RRTM. The committee has met with a broad cross section of the offshore industry and has seen how RRTM is being applied in drilling and production operations. It appreciates the decade-long journey that several companies have undertaken to advance the technologies and operating practices to where they are today.

Previous studies that reviewed the use and application of real-time technologies in the offshore oil and gas industry have identified the breadth of experience across the U.S. industry (see BSEE 2014 and 838, Inc. 2014). Both of these studies outlined potential applications of RRTM, but neither provides a road map for how to realize this potential. Some of the largest operating companies in the Gulf of Mexico use RRTM in their exploration or production activities, but they represent only a fraction of the offshore drilling and production industry. As noted at the committee's April 2015 workshop, there are no current standards for the application of RRTM, nor is there a fundamental consensus with regard to the business case supporting its use (see TRB 2015).

The offshore oil and gas business is not a simple undertaking. The operations are complex, as is the operating environment, where risk can be dominated by subsurface unknowns. The industry solution for

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managing this and other risks is a complex array of technologies deployed by a large number of operating, service, and specialist companies. The data flows are also complex, with real-time data flowing to the drilling contractor for decision making and a large portion of those data flowing from the drilling contractor to the operating company. Modern exploration and production workflows can require the integration of data from multiple contractors, who often use technical applications from diverse software vendors.

Whereas individual companies have developed an independent view concerning the value of RRTM and customized its application to meet an individual business case, some fundamental beliefs about RRTM are consistently held across the industry. First, there is recognition that those closest to the operations, whether personnel on the MODU or the production platform, are in the best position to make operational decisions and that decision-making authority should remain offshore.

The technologies that make RRTM possible—for example, sensor and communications technology—will continue to develop and will create greater possibilities. At its workshop, the committee was told that the collection of RRTM data can have additional benefits and uses. For example, it can help in synthesizing incoming data and information from multiple sites, in providing a knowledge base for postmortems after incidents and in tracking lessons learned, and in improving decision-making tools. Industry and previous studies continue to promote RRTM's future, but there does not appear to be consensus as to what that future looks like. The industry does appear to agree that RRTM is one of many tools that support safe and efficient offshore operations. RRTM and its impact are likely to evolve, but at present the industry does not perceive RRTM as a way to change drastically how work is done in offshore operations.

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Abbreviations

BSEE	Bureau of Safety and Environmental Enforcement
NAE	National Academy of Engineering
NRC	National Research Council
TRB	Transportation Research Board

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3

Benefits of and Considerations for Remote Real-Time Monitoring

In Chapter 1, the nature of real-time monitoring (RTM) and remote RTM (RRTM) activity in the oil and gas industry was introduced, along with the priorities of the Bureau of Safety and Environmental Enforcement (BSEE) and the charge of this committee. Chapter 2 provided a brief overview of offshore drilling and production operations and described the use of RRTM in the oil and gas industry. The last section of Chapter 2 summarized key points from two previous reports on the application of RRTM (BSEE 2014; 838, Inc. 2014) and from the summary of an industry workshop held by the committee (TRB 2015).

Chapter 3 begins with a brief examination of best available and safest technology (BAST) as it relates to RRTM. Next, the notional benefits of RRTM in the oil and gas industry are illustrated with four use cases. The cases do not represent the full potentiality of RRTM, but they illustrate possible applications. After this presentation, several considerations for applying RRTM to the delivery of these use cases are examined by discussing issues such as data management, cybersecurity, and human factors. Finally, the potential role of RRTM in risk-based regulations and the possibility of using real-time data for condition-based maintenance (CBM) are considered.

RRTM AS BAST

The Outer Continental Shelf Lands Act mandates the use of BAST in offshore drilling and operations "wherever practicable" and "economically feasible."[1] After the Macondo well blowout and *Deepwater Horizon*

[1] See Public Law 95-372, Section 21(b): "[T]he Secretary . . . shall require, on all new drilling and production operations and, wherever practicable, on existing operations, the use of the best

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explosion, BSEE requested a study from the National Academy of Engineering (NAE) and the National Research Council (NRC) that would provide options for improving the implementation of BAST. The final report (NAE and NRC 2013) provides insights into the meaning of BAST and identifies and evaluates specific technologies. More recently, BSEE developed a three-stage process for identifying candidate technologies for BAST determinations on the basis of an evaluation of the best-performing technology that is currently available. The director of BSEE initiates the BAST determination process and makes the final BAST decision.[2]

The current committee views RRTM in the context of BAST and believes that, as a technology that could reduce risks in particularly complex wells or projects, it could become more generally available to the offshore oil and gas industry and be a part of its tool kit for appropriate situations. By describing RRTM as BAST, the committee is not suggesting that its use be made mandatory on all wells. If RRTM is determined to be BAST by the director of BSEE, it could be considered an appropriate technology for monitoring operations and managing risk, and its use could be evaluated against the framework developed by the previous NAE-NRC BAST committee, as outlined in the following paragraphs.

RRTM has developed over the past decade as technology improvements have allowed the transfer of increasing volumes of data to remote locations for monitoring and evaluation in real or near real time. For the offshore industry, the remote location is typically the onshore offices of the operator or selected contractors. The increasing capability for managing data has in effect pushed the technology into wider implementation as companies identified opportunities to utilize RRTM to manage complex operations more efficiently, engage onshore expertise, and improve the management of safety.

At the same time, the increasing complexity of many offshore drilling and producing operations (e.g., greater water depths, high-pressure or high-temperature subsurface environments, and increasing physical

available and safest technologies which the Secretary determines to be economically feasible, wherever failure of equipment would have a significant effect on safety, health, or the environment, except where the Secretary determines that the incremental benefits are clearly insufficient to justify the incremental costs of utilizing such technologies."

[2] More detail about the BSEE BAST determination process can be found at http://www.bsee.gov/bast/.

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scale for equipment and operations) has created a technology pull, whereby new solutions are needed in technology deployment for cost-effectiveness and better safety management.

The decision whether to utilize RRTM on any particular well must recognize the complexity of the operating environment and of BAST implementation. RRTM must be evaluated as a candidate technology for managing risk, with consideration given to the overall complexity of the engineered and human systems.

Consistent with the BAST committee's framework, any implementation of RRTM as BAST could be considered relative to its potential contributions to overall safety, consistent with the principle of ALARP (as low as reasonably practicable),[3] where practicability is interpreted as encompassing both technological availability and economic feasibility.

NOTIONAL BENEFITS OF RRTM

Traditionally, industry has used RRTM to improve efficiency and effectiveness through drilling optimization and better well planning and execution. In the following section, the committee presents four high-level illustrative use cases that provide examples of the notional benefits of applying RRTM:

- RRTM and wellbore integrity and early kick detection,
- RRTM enabling augmented competencies from onshore,
- BSEE regulatory oversight and inspections with the help of RRTM, and
- RRTM and CBM of critical equipment.

RRTM and Wellbore Integrity and Early Kick Detection

Monitoring for well integrity and control, particularly early kick detection, is one of the most important challenges for offshore operations. Well integrity has multiple facets and often refers to the application of technical, operational, and organizational solutions during the life cycle of a well to reduce the risk of uncontrolled release of formation fluids.

[3] http://www.iadclexicon.org/as-low-as-reasonably-practicable/.

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A "kick" refers to the entry of formation fluid into the wellbore (or drilled hole) during drilling operations. It can occur when the pressure exerted by the column of drilling fluid is not great enough to balance the pressure exerted by the fluids in the formation being drilled. Kick prevention is a fundamental aspect of well integrity and control. If kicks are not addressed appropriately, they can lead to loss of well control and to a blowout.

Offshore personnel must perform RTM of drilling operations and equipment status. For example, the driller is primarily responsible for monitoring the parameters associated with well control. At the offshore facility, monitoring by the driller is backed up by the mud logger or the drilling superintendent (also known as the company man), or both. Before the ready availability of broadband data at onshore office facilities, the role of remote personnel was limited to after-action review and long-term trend monitoring. The availability of significant real-time information to onshore locations has led to the possibility of additional and more complex monitoring of critical activities. However, the nature of these data is diverse and distributed. Many of the crucial data are collected by the mobile offshore drilling unit (MODU) operator, but some critical data are also collected by third-party service providers. Historically, the lease operator may not own or be provided with all the data that are generated on a MODU.

Command and control issues become more complex when an RTM component is added. According to universal practice, the on-site commander (i.e., the driller) is in charge of real-time decision making. The addition of remote monitoring centers raises the possibility of confusion concerning who is in charge and of distractions during emergency or time-critical operations. Theoretically, monitoring centers can support detection of incipient problems, since onshore, remote personnel are less vulnerable to the distractions and concerns experienced by onboard MODU personnel. However, not all the data are available to onshore remote personnel, especially with regard to situational awareness data—data helpful in understanding what is occurring on the offshore facility. Data without context could lead to erroneous decision making.

RRTM could be effective if comprehensive data are provided from the MODU and if roles and responsibilities for decision making are well

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defined. Such changes in data collection would require modifications of commercial arrangements and contracts, as well as hardware and software connectivity.[4] The technical problems of transmitting and displaying the data may be the least difficult aspect of RRTM.

As mentioned above, the driller monitors parameters downhole at the MODU to detect kicks. The parameters include mud pit levels, pump volumes, various pressures on the rig floor, and downhole measurements. Situational awareness of valve positions, piping runs, and other rig activities—such as crane operations—is important, as are the values of mud weight and returns. The driller has other concurrent responsibilities and multitasks between monitoring well control parameters and operating the necessary equipment.

RRTM for early kick detection would require all the information that is provided offshore, but it could focus on well control, if desired, and exclude anything else. RRTM for kick detection must not replace offshore personnel as the primary control for this hazard. Caution must be taken to ensure that offshore personnel do not become so reliant on onshore RRTM that they lower their surveillance of critical parameters.

A short checklist of the necessary conditions for effective RRTM for early kick detection includes the following:

- The right data must be provided to the remote location, including situational awareness information.
- The remote (onshore) personnel must be trained and competent, and preferably experienced, in well control monitoring.
- Collaboration without distraction and a well-defined protocol for interaction with offshore personnel are required through a direct line of communication.
- The remote personnel must not be burdened with monitoring an excessive number of operations or with office activities.
- The remote personnel must have ready access to additional onshore expertise in the areas of well design, engineering, and geophysical information and interpretation.

[4] A. Jaffrey, Cameron, presentation to the committee, August 2015.

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- The onshore expertise must be available for consultation with the offshore personnel.
- A clear line of communication and communication protocols must exist between onshore and offshore personnel.

Even with state-of-the-art technology, the most reliable kick detection is via experienced personnel on the rig. The committee acknowledges that the industry has invested in and continues to work on smart systems, which could aid in early kick detection, but is unaware of any proven commercially available automated kick detection software or other system that provides warning of a pressure problem during drilling operations. Dual gradient drilling[5] is one example of a method for enhancing kick detection through better fluid monitoring capabilities, and RRTM serves as a key enabler of this technology.

RRTM Enabling Augmented Competencies from Onshore

RRTM started with the desire of many operators to apply real-time information from downhole sensors to their operational decision making, such as formation evaluation, casing depth setting, and completion strategy. Once the data were collected and transmitted back to shore, the operator was better able to engage with a global group of situation-specific, technical experts. In turn, some operators chose to develop formal RRTM facilities and created protocols for interacting with personnel on the MODU.

With the appropriate communication protocols in place, RRTM can enable additional competencies located onshore to support a decision offshore. RRTM centers monitor fleet operations—where the term "fleet" describes like equipment or like parameters—across multiple drilling or production facilities and provide checks relating to key activities. While complexities and challenges with regard to data quality, data transmission, and data management exist, RRTM operations facilitate the comparison of historical and real-time, fleet-based operational data,

[5] Dual gradient drilling holds promise for enhancing early kick detection. See http://oilprice.com/Energy/Energy-General/Chevron-has-Unveiled-New-Ship-to-Perform-Dual-Gradient-Drilling.html.

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including topics such as nonproductive time and blowout preventer (BOP) availability. Empirical data collected at the fleet level are essential for validating and iterating predictive maintenance models such as CBM and, in turn, increase the value that RRTM can provide over the long term.

RRTM facilities generally replicate instrumentation and screens used in monitoring critical offshore systems. Remote monitoring centers can provide core onshore resources for well operations planning and for decision support for offshore operations. If experienced engineers, geologists, and other technical specialists are located at the remote center, the ability to solve problems during drilling and completion activities also improves. Real-time events occurring offshore can be analyzed and interpreted—on a permanent or on-call basis—by the technical expertise in remote centers. The centers, located worldwide, enable quick collaboration with onshore specialists, engineers, and management without the need of flying them offshore, which is time-consuming, delays decision making, and increases overall safety risk. By adopting RRTM into their operations, operators, service providers, and original equipment manufacturers (OEMs) have access to the entire office staff in real time, without the safety risk exposure and travel time associated with trips offshore. Many operators also reported improved efficiencies when they used RRTM to engage onshore resources in a timely manner.

BSEE Regulatory Oversight and Inspections with the Help of RRTM

One of BSEE's goals for using RRTM is to reduce the costs and risks associated with the offshore presence of regulators. The BSEE inspection and enforcement program could use the information from RRTM and from other filings by offshore operators to focus limited resources on critical operations and improve preparation of inspectors before on-site visits. For example, inspectors could research operation plans, permits, and prior inspections and perform paperwork duties before the offshore visit. Archived RRTM data could also support the risk-based regulatory program that BSEE has adopted, which is discussed in more detail at the end of this chapter. The information would come not only from RRTM operations but also from required documents, such as the Application for Permit to Drill, the Deepwater Operations Plan, and the Safety and

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Environmental Management System (SEMS) plan; daily drilling reports; and historical information from past operations and an industry knowledge base.

The internal BSEE RRTM report illustrates several ways in which information collected from an operator's RRTM process can help inspectors get better prepared (BSEE 2014). RRTM, in itself, may not cut down on the number of offshore visits, but it could make inspectors more effective and efficient on each visit. As noted at the committee's April 2015 workshop, offshore operators prefer that inspections continue to be on site, but they are willing to host inspectors in their onshore drilling and production support centers. The lack of standardization in RRTM solutions used by the industry will make the training of BSEE inspectors in the various solutions challenging. However, reduction by BSEE of the number of on-site inspections may be difficult as long as regulations require periodic inspections of each offshore facility. A later section in this chapter describes in greater detail how BSEE could integrate RRTM into a risk-based regulatory approach.

The BSEE internal report discussed various scenarios for incorporating RRTM into its safety and environmental enforcement program (see BSEE 2014). However, to accomplish this, operators with established onshore RRTM centers who presented to the committee indicated that the following elements need to be considered before a commitment is made to an RRTM center:

- The investment needed to set up the infrastructure for RRTM and to operate,
- Development of standards and a formalized operational workflow,
- Specific communication protocols required for the interaction between onshore analysts and offshore operators,
- Specialized skill sets needed by RRTM staff, and
- Understanding and appropriate use of monitoring tool technologies.

Any organization considering establishment of an RRTM capability will need to investigate each of these elements carefully before proceeding. BSEE noted in its report that implementing any RRTM program (from visiting an operator's center to establishing its own center) would be a change from its current inspection program and would require skill

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sets different from those used in BSEE's traditional inspection activities (BSEE 2014). BSEE personnel involved with RRTM operations would need to have the proper qualifications, experience, and technical training to contribute to the safety of complex offshore drilling and production operations. The committee acknowledges that recruiting and retaining personnel with these skills could be challenging for the federal government.

Under RRTM, the operator will still be accountable for safe operations on the offshore facility. RRTM could assist BSEE in improving regulatory oversight of critical operations. However, close involvement with an operator's RRTM operations will raise issues such as protection of proprietary information, avoidance of confusing communications, potential legal liability of sharing information, the repercussions of shutting down a well, and the complex context or situational reality on the MODU or offshore facility. As reported to the committee through its workshop, the deployment and use of RRTM by industry exhibit varying levels of maturity among companies. Maintaining personnel with the necessary competencies for staffing a remote center is difficult. Technologies in use by the industry differ and can change over a short time. The objectives of requiring the use of RRTM need to be specified before industrywide standards can be developed. Until then, individual companies will follow their own internal guidelines and best practices. The subsequent section of this chapter on risk assessment and risk-based regulations expands on this notional example with a deeper discussion of opportunities and challenges of applying RRTM to assist BSEE in its regulatory oversight.

RRTM and CBM of Critical Equipment

Onshore parameter monitoring and CBM of critical safety and operational equipment on the MODU are emerging areas within RRTM. Although the oil and gas industry can cite remote monitoring examples that have been deployed for more than two decades, the application and breadth of such RRTM examples are limited. In general, the oil and gas industry and other industrial segments such as transportation are experiencing a merging of operational technologies, such as rotating equipment, pressure control equipment, and helm-based systems, with traditional information technology infrastructure. Performance-based or uptime models that rely

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on sophisticated data management and data analytics are also arising, with a long-term objective of CBM.

One trend has been the increased sophistication of on-equipment control systems. They can capture many parameters that collectively describe the equipment's use, such as cycle counts, housekeeping data, and state of operation. Such systems often can call home and in many cases provide the remote operator onshore with read-only access to all the system configuration screens that a MODU technician could access. These control systems may also be able to upgrade system software or firmware remotely, and some systems—if enabled—can control equipment fully from onshore. Such remote capabilities enhance the provision of support from available onshore expertise when problems occur.

Early adoption of remote monitoring has occurred in three areas: the more recent generations of BOPs, subsea production, and MODU rotating equipment (such as power generation and compression).[6] The benefits of this approach are linked mainly to operational efficiency associated with the equipment and elimination of unplanned outages, but a longer-term goal could include CBM services (Jaffrey 2015).

RRTM facilities generally replicate instrumentation and monitoring screens used to operate mission-critical systems deployed offshore and include systems such as BOPs, mud circulation systems, downhole tools, and subsea production controls. By using familiar interfaces and aggregated historical trend data, expertise located onshore can—on a permanent or on-call basis—analyze and interpret real-time events occurring offshore. In the near term, RRTM operations can provide enhanced situational awareness and augmented competencies to decision makers located offshore. In the longer term, onshore RRTM facilities will likely become a primary conduit for fleet data and serve as the basis for predictive modeling and CBM.

A greater array of deployed sensors and the ability to aggregate fleet maintenance data are two preconditions for CBM programs. Maintenance of sensors and their proper calibration and reading are essential for CBM. CBM provides service life-cycle enhancements, with the aim of fundamentally changing service from an interval basis to a predictive basis. The

[6] For an early subsea example, see http://offshore.no/sak/52607_more_subsea_monitoring_for_snohvit.

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benefits to the operator working offshore are significant and include increased equipment uptime, a long-term objective of no unplanned outages, and a better planning horizon for necessary interventions. Recently, Diamond Offshore and GE Oil and Gas entered into a 10-year arrangement for selected BOPs that mimics similar performance-based or uptime models in use within aviation and other industry vertical markets.[7] Fundamentally, these business models shift ownership and performance accountability of the asset to the OEM. Since uptime is the primary payment criterion, these long-term contracts provide an incentive for the OEM to aggregate and analyze real-time and historical data for improved equipment availability, better safety, and, ultimately, prognostics (predictive modeling and CBM). This approach simplifies technology pull and allows the OEM to pursue technology upgrades (e.g., sensors, control systems) across an OEM-owned BOP fleet with greater efficiency and expediency.[8] The advent of these models in the BOP segment as well as in other on-rig equipment (turbines, compressors, pumps) will bring about new dynamics, including business models that benefit from an increased reliance on predictive capabilities that aspire to CBM.[9] Over time, greater adoption of RRTM will drive the necessary data standards, data infrastructure, and data systems to realize the potential of CBM. A later section of this chapter, Potential of CBM and RRTM, expands on how RRTM could advance CBM and discusses some of the challenges that would need to be addressed to do so.

Summary

The preceding four high-level use cases do not represent the full potentiality of RRTM, but they illustrate applications that differ in scope and context. For more than two decades, industry has used RRTM to improve

[7] In a vertical market, businesses cater to the needs of a particular industry, such as aviation. See also http://www.maintenancetechnology.com/2012/06/the-rolls-royce-of-effective-performance-based-collaboration/.

[8] The assumption is that the OEM can deploy updates into the fleet more effectively given direct ownership of the assets, which simplifies the technology commercialization cycle to some degree.

[9] For example, see Diamond Offshore Drilling's pressure control by the hour model, http://investor.diamondoffshore.com/phoenix.zhtml?c=78110&p=irol-newsArticle&ID=2136291, and GE's engageDrilling Services, https://www.geoilandgas.com/drilling/offshore-drilling/engagedrillingtm-services-contractual-service-agreements.

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efficiency and effectiveness through drilling and optimization and better well planning and execution. These efforts helped bring about formalized remote operations centers that can use competencies available onshore to increase overall efficiency of remote drilling and production operations. In addition to driving better support for decision making, real-time competency augmentation from onshore decreases the need for travel offshore, which in turn enhances safety.

The state of the art of RRTM could notionally support enhanced regulatory inspection from offshore, although industry expressed concerns with regard to the scope and breadth of such initiatives. BSEE and industry collaboration to determine how RRTM could support or enhance traditional on-rig inspection regimes was generally encouraged at the committee's workshop. Options concerning how BSEE could integrate RRTM into a risk-based regulatory approach are discussed later in this chapter. The fourth use case, on the potential of CBM, introduces the need for persistent, high-fidelity sensor data from equipment to train or validate predictive models. RRTM can provide operators, service companies, and OEMs with vital empirical data for developing CBM. The potential of CBM is examined in greater detail in the last section of this chapter.

CONSIDERATIONS AND CHALLENGES FOR RRTM

The use of real-time data is increasing, especially as sensor technology advances and as the ability to transmit that data improves. At its April 2015 workshop, the committee was told about the importance of reliable and consistent sensor data for RTM, and the basis for any RRTM endeavor is reliable and valid data. Remote centers could help achieve this goal by checking the incoming information stream and allowing the development of a knowledge base and additional postprocessing data analysis, which leads to analysis and decision making.

As noted in Chapter 2, the authors of the 838, Inc., report discuss the importance of collecting, managing, and analyzing reliable and valid data in the context of the digital oil field. The authors surveyed sensor technologies used by industry to measure and report performance and to predict failure of monitored equipment. They note that advancements in sensor technology have allowed industry to increase the amount and improve the quality of data collected from critical systems, which has

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led to more efficient and reliable equipment. According to the authors' research, the data recorded are only a subset of the total available data. As more data are collected and recorded, industry will need better methods of data storage, transmission, and analysis (838, Inc. 2014). Remarkably, fewer sensors are installed on subsea equipment, for reasons such as cost, the absence of regulations, and the lack of standards (Jaffrey 2015).

Several data management issues must be addressed when an RRTM center is set up. The success of such a center in adding value to the drilling or production operations being monitored obviously depends on the technical expertise available onshore as well as the protocols established for intervention. The center's success could also depend on how effectively numerous data management issues are addressed. The remote center staff and any onshore expertise that is accessed through the center will be limited by what data are available to them, how those data are managed in real time, and how data are stored and managed for the longer-term uses of trend analysis, lookbacks, and investigations.

Data Management and Technological Concerns for RRTM

The committee has identified some of the data management issues with particular relevance to RRTM. The following review is not exhaustive, but it highlights the kinds of issues and questions about data and data management that will need to be addressed in establishing and running an RRTM center.

Data Capture and Data Streaming

Large volumes of data are available offshore, but where companies currently operate real-time centers, only a small percentage is actually transmitted to shore. For example, one operator at the committee's April 2015 workshop estimated that one of its drilling rigs provided more than 6,000 streams of data, yet the operator transmitted only about 60 of those data streams to the remote onshore center. The choice of what data are transmitted is critical. Bandwidth limitations for transmission to shore will typically influence those choices. Regardless of what data are transmitted, the lack of situational awareness onshore is an important issue in today's operations.

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Data Management

Real-time data on a MODU or a production platform are first aggregated offshore in a specialized data store for sensor and process control system data, or an electronic data recorder. This establishes a beginning point for data ownership by the operator. In RRTM, an onshore data warehouse can be established as a repository for integrated data used for reporting and data analysis. Under the traditional approach to managing offshore data, maintenance of the appropriate balance between data access and data confidentiality among all the parties is difficult. When data protection is emphasized, data distribution is limited, and often critical data are not shared among all parties that need the information. This can defeat the purpose of the RRTM center, since onshore staff may not have full access to the data necessary to support offshore operations and decision makers. If data access is emphasized, data ownership and confidentiality can be violated. Without a complete systems view of the data life cycle, these factors are difficult to manage. Furthermore, if establishment of remote centers means that real-time data must be transmitted to government entities, industry might require additional guarantees on data protection and data security—what data are required, how the data will be used, and who will have access (TRB 2015).

Data Quality and Integrity

As offshore installations become more heavily instrumented and as advances in communications technology allow more data to be streamed to shore, operating practices need to evolve to support the new data systems. Sensor maintenance and data integrity will be critical. Limited data transmission could result in lower levels of data redundancy in the remote center, and therefore the data that are available must be trustworthy.

Data Governance and Ownership

Implementing data governance means translating business needs into business and data management processes. Roles and responsibilities for collecting and managing all types of data must be defined, and cross-functional data standards must be applied. Data protocols, such

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as WITSML and PRODML,[10] ease the difficulty of exchanging data between systems and companies. Good data governance manages the data relationship between offshore facility and onshore center. Current contracts between operators, drilling contractors, and service companies often lack specific requirements for collecting digital data and fail to define the responsibilities of each party in managing, distributing, and processing data from the field. Furthermore, few (if any) standards exist for collecting the data needed for remote monitoring (Jaffrey 2015). Issues such as proprietary data streams managed by the operator or various contractors add to the technical data collection and interpretation challenge. Current data practices make holistic, data-driven actions and decisions difficult or impossible in an onshore support center.

Data Integration

Typically, in offshore operations data integration means merging subsets of operating data from the exploration, production, and accounting functions. For RRTM, this level of integration falls short. The integration of data must span the entire value chain and link diverse data sources and types. To realize the full potential of RRTM—including the implementation of CBM—capturing and linking data across the life of a component or facility will be necessary, regardless of where the component or facility is located or who is the owner. An integration framework allows the seamless transfer of information through proper data management practices, reports, and operational dashboards. The purpose of an integration framework is to enable the transfer of information between various functions and applications according to a defined workflow and to enable the presentation of information in a way that facilitates decision making—in a word, interoperability (Crompton and Gilman 2011).

Analytics

Many of the data collected from RTM during the drilling process will become more useful as big data applications for the oil and gas industry

[10] WITSML (Wellsite Information Transfer Standard Markup Language) is a standard for sending wellsite information; PRODML (Production Markup Language) is a standard for drilling and production data.

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are developed in the near future. These data will allow companies to analyze just-in-time options for the oil field, to improve control of their drilling programs and rig schedules, and to have better insight into supplier contracting possibilities. The foundation for realizing these benefits is proper design of an RTM system.

Emerging Technologies

The impacts of several emerging technologies have yet to be felt fully within the offshore industry. These technologies could affect the design and operation of RRTM and monitoring centers within the foreseeable future. Among them are the following:

- **Big data platform** would bring issues concerning the volume, speed, and diversity of real-time data into clearer focus.
- Under **cloud computing**, infrastructure-as-a-service would challenge the industry's traditionally conservative position on data privacy and security.
- Under **advanced analytics**, functional and operational models (e.g., reservoir modeling or geosteering) use real-time data to develop insights and manage work processes in real time.
- **Mobility** makes more real-time data available on mobile platforms in more locations and locations far from a remote monitoring center, and companies take advantage of this data availability to improve the management of business processes, further challenging long-held models for data management and security.
- **The industrial Internet of Things** will enable the growth of oil field sensor and control systems and provide more data to staff in remote locations that will produce more timely interventions and improve operational insights.

As stated earlier, this section is not intended as a complete review of data and data management challenges in RRTM. Instead, it highlights the more significant challenges that the committee identified and briefly frames these issues in the context of the development and application of RRTM. Most of these challenges were raised by members of industry during the April 2015 workshop and during visits by the committee to operating and service companies throughout 2015.

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As more companies use RRTM in managing offshore operations, the scope of these issues will grow from single-company problems to industry-wide challenges.

Cybersecurity and RRTM

Connectivity and communication between onshore and offshore facilities are important in efficient and safe offshore operations (TRB 2015). Connecting onshore and offshore facilities has been motivated by operators' desire to "increase productivity, reduce costs, and share information in real time across multiple industrial and enterprise systems" (Byres 2012). With increased reliance on connected devices and software-aided decision making, the risks posed by cyber-based threats have grown since the beginning of the preceding decade. In addition, process equipment depends on computer technology to a greater extent, which creates computer-based vulnerabilities independent of connectivity. According to the Repository for Industrial Security Incidents, half of all security and safety incidents related to industrial control systems reported from 1982 to 2010 were due to malware, external attacks, or internal attacks (Byres 2012), which suggests the need to mitigate a broad set of vulnerabilities.

Increased use of RRTM of offshore operations and equipment will place new demands on the instrumentation of drilling and production equipment and further drive demand for connectivity and bandwidth for offshore operations. The increased use of mobile devices to display information has added risk (TRB 2015, 33). Operational technology systems, such as legacy programmable logic control (PLC) systems and supervisory control and data acquisition (SCADA) systems for mission critical rig-based equipment, were not designed for connectivity to Internet-facing systems and were not necessarily designed to be resilient to computer-based incidents that corrupt or alter software in an unauthorized way, whether intentionally or unintentionally (Hsieh 2015). Modern MODUs feature many systems that are Internet-capable, but they lack "awareness of true risks and governance to ensure proper cyber risk management" (Endress 2015).

Traditionally, control system networks were air gapped or separate from Internet-facing networks, which minimized accidental or malicious

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attacks.[11] To a greater extent, control systems have been connected to Internet-facing networks, which allow more effective asset management and greater process efficiency. This connectedness can increase exposure of control-system-based targets, such as SCADA- and PLC-based systems, and increase potential pathways (or points of entry) (Byres 2012).

Safety and security threats are expected to grow, which suggests a need to focus on issues related to physical harm or the environment. The Stuxnet[12] computer worm is an example of a computer-based attack, and a news report indicated that a German steel plant was damaged by a computer attack in 2014.[13] Documented cyberattacks on oil and gas facilities include a 2008 oil pipeline explosion in Turkey and a 2012 virus that infected up to 30,000 computers on Saudi Aramco's network (Hsieh 2015). According to the Ponemon Institute, companies in energy and utilities recorded increased annual costs due to cybercrime,[14] and an ABI Research study predicted that global cyberattacks against oil and gas infrastructure could cost companies up to $1.87 billion by 2018.[15] PriceWaterhouseCoopers reported that cyberattacks in the oil and gas industry during 2014 increased from the previous year and will likely continue to do so.[16]

Vulnerabilities specific to control systems include poor risk analysis; poor design, testing, certification, and hardening of control system equipment; poor awareness and management of the vulnerabilities; and human error (Johnsen 2012; DNV GL 2015). The vulnerabilities can be mitigated and controlled through systematic work focusing on cybersecurity and cyberphysical threats. Key vulnerabilities can be managed through the use of risk management and rule compliance measures (Hopkins 2011; ABS 2016).

The response to such threats has included comprehensive guidelines that define procedures for implementing electronically secure systems.

[11] Although these control systems were designed with an air gap, in reality, over time, many of these systems were linked to Internet-facing systems.

[12] An overview of Stuxnet is available at http://spectrum.ieee.org/telecom/security/the-real-story-of-stuxnet/.

[13] http://www.bbc.com/news/technology-30575104.

[14] http://www-03.ibm.com/security/data-breach/.

[15] https://www.abiresearch.com/whitepapers/petrosecurity-in-the-digital-era/.

[16] http://www.pwc.com/us/en/increasing-it-effectiveness/publications/assets/pwc-2014-us-state-of-cybercrime.pdf.

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The guidelines apply to the many stakeholders, including end users and OEMs, who design, manufacture, implement, or manage industrial control systems. The guidelines include the International Society of Automation (ISA) and the International Electrotechnical Commission (IEC) 62443 set of standards and other documents,[17] which describe the elements needed for a cybersecurity management system for industrial control systems and provide guidance on how to meet the requirements for each element. Extensive guidelines are also offered by the National Institute of Standards and Technology (NIST), including NIST's Framework for Improving Critical Infrastructure Cybersecurity, which offers practical suggestions for cybersecurity.[18] In a more controls-specific context, the Norwegian Oil Industry Association (Oljeindustriens Landsforening or OLF) provides recommended guidelines for information security baseline requirements for process control systems (see OLF 2009).[19]

MODUs feature systems that are Internet-capable, which increases demands for instrumentation of offshore equipment and for transmitted data, connectivity, and bandwidth from offshore. As more RRTM of offshore operations is introduced, the cybersecurity risks associated with the technology rise. Recently, the U.S. Coast Guard (USCG) released its cyberstrategy,[20] which outlines its plan to work with industry and to manage cyberrisks to maritime-critical infrastructure. A final USCG policy is expected in 2016. The International Association of Drilling Contractors (IADC) Cybersecurity Taskforce is scheduled to release draft guidelines in 2016. They are based on ISA–IEC and NIST standards that will emphasize a risk assessment methodology (Hsieh 2015). Although BSEE is collaborating with USCG on cybersecurity issues, the agency has not released an official cybersecurity policy. The broader introduction of RRTM to offshore operations heightens cybersecurity risks for the industry and makes their evaluation more critical.

[17] https://www.isa.org.

[18] http://www.nist.gov/cyberframework/.

[19] https://www.norskoljeoggass.no/en/Publica/Guidelines/Integrated-operations/104-Recommended-guidelines-for-information-security-baseline-requirements-for-process-control-safety-and-support-ICT-systems/.

[20] USCG Cyber Strategy is available at https://www.uscg.mil/seniorleadership/DOCS/cyber.pdf.

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RRTM and Human Factors Considerations from the National Aeronautics and Space Administration

Research on human factors is diverse and multidisciplinary. It traditionally includes areas such as ergonomics, cognitive factors, and organizational factors, all of which can influence work design, resilience, operations, and safety. The following section is intended to present several examples of human factors from the National Aeronautics and Space Administration (NASA) that are relevant to RRTM of offshore oil and gas operations—specifically, the development of communication protocols. As more data are shared, the need to focus on communication protocols and the interactions of human actors grows. NASA's experience indicates the importance of incorporating human factors principles through better communication protocols, which can often lead to improved shared situational awareness and team collaboration.

The importance of communication protocols and team collaboration is supported by human factors research. For example, Salas et al. (2005) identified five central components of teamwork: leadership (ability to direct and coordinate activities), mutual performance monitoring (ability to understand and monitor team environment), backup behavior (ability to anticipate and shift workload among the team), adaptability (ability to adjust strategies on the basis of input or changing conditions), and team orientation (prioritize team's goal over individual's goal). In addition, the authors suggest that these core components of teamwork are facilitated by the three coordinating mechanisms of shared mental models (i.e., common understanding of responsibilities and procedures), closed-loop communication (i.e., standard exchange of information between team members), and mutual trust (i.e., expectation that team members will perform roles accordingly) (see Salas et al. 2005).

Over the course of its study, the committee visited several RRTM facilities for offshore drilling in the Houston area, including those of Shell, Chevron, Anadarko, Schlumberger, and BP. In all cases, the discussions reinforced the view that human factors, organizational culture, and interpersonal relationships were key elements in the success of the RRTM operation. The visits illuminated many of the subjects discussed by industry representatives during the committee's April 2015 workshop (see TRB 2015).

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In addition to the RRTM centers above, the committee toured NASA's Johnson Space Center and Mission Control for the International Space Station (ISS) to gain a slightly different perspective on remote real-time centers. Although this facility serves a command and control function as well as an RRTM function, some lessons from the NASA visit illustrate issues in offshore drilling RRTM.

As are hardware, software, and communications capabilities, human factors are critically important in the success of NASA's operation. The first important element of human factors is a well-understood definition of roles and responsibilities that is determined and communicated to all parties. The responsibilities of the on-scene commander (known as the spacecraft commander) must be clearly defined. Similarly, the roles and responsibilities of the remote personnel and their management must be delineated. Training is required to ensure that all personnel understand roles, responsibilities, and the structure of the chain of command.[21] The second important element is close interaction of the remote team demonstrating its support for the on-scene team. In its absence, interpersonal friction will impede the success of the operation. In particular, the on-scene personnel (i.e., NASA's astronauts) must be convinced that the remote team adds value and is not merely monitoring to record operator errors. The interaction starts with face-to-face meetings between team members before the on-scene (crew or offshore) team departs.

In most remote operations, situational awareness with regard to events at the scene is critical. Where the RRTM center is merely advisory or serves as a backup, maintenance of situational awareness is desirable but not mandatory. In these cases, offshore (on-scene) personnel can directly communicate, as time permits, with the RRTM center to establish the center's situational awareness. As functional requirements for the RRTM center grow, continuous situational awareness of the RRTM personnel becomes more important.

Some U.S. operators have proposed that remote monitoring will allow functions to be taken off of the MODU and performed onshore by

[21] An important concept for NASA in achieving proper training is crew resource management (CRM) training. More information on CRM's application to oil and gas operations is provided by OGP (2014).

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RRTM personnel. The NASA space flight experience requires that much of the monitoring of systems performance be completed remotely, given the small number of crew members on board the International Space Station (ISS) (or previous vehicles) and the inherent complexity of the systems in operation. The on-scene team is simply too small to monitor all critical functions at all times. In addition, the most important use of the on-scene spacecraft crew (or potentially the offshore MODU team) is to do the things that can only be done at the site. Offloading the monitoring of basic systems from the on-scene team to the ground (remote) personnel has been a necessity of human space flight. This feature has driven an extensive protocol concerning standard instrumentation, including multiple redundant instrumentation points measuring critical parameters.

A process for determining whether a particular instrument is operating correctly and the protocol to be followed after an instrument has failed is also standard. Maintenance of instrumentation, including correct calibration, is a strong feature required in RRTM of human space flight. These paradigms differ significantly from current offshore drilling practice. Advanced practices concerning instrumentation and measurement will be critical if primary responsibility for monitoring the operation of offshore equipment is to be moved onshore. However, as long as the RRTM function is merely advisory or a backup to the on-scene personnel, instrumentation requirements may continue to be less strict.

Above all, clearly defining and communicating protocols for the roles and responsibilities for both offshore (on-site) and remote (onshore) teams are important for any offshore oil and gas RRTM endeavor. Proper training is required to ensure that all personnel understand roles, responsibilities, and the structure of the chain of command, especially to demonstrate the remote team's support of the on-site team. Maintaining situational awareness in the RRTM center is important but not mandatory as long as the center remains in an advisory or backup role.

RISK ASSESSMENT AND RISK-BASED REGULATIONS

As noted in Chapter 1, BSEE has sought to improve its offshore safety program by integrating RRTM technologies with an enhanced SEMS. Using more risk-based criteria would bolster BSEE's risk-based regulatory

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program and allow the agency to prioritize which inspections and SEMS audits it should observe.

The idea of risk-based regulation and inspection activities has been used by regulatory agencies for many years. It appeals to the simple intuition that inspections should be focused on facilities and operations where circumstances suggest that additional monitoring would be most effective. A risk-informed approach is used by identifying a hazardous event, determining its likelihood, and specifying its consequences. The expected risk is represented by the product of the likelihood and the consequences of an event and is often presented in the form of a matrix.[22] These calculations can be used as an input to establish priorities for inspection and risk mitigation activities. The risk-informed regulatory and inspection approach is often fostered by identifying the adverse events that are the focus of the agency and is based on a series of steps that are carried out and revised on a continual basis. Such a process can take advantage of historical data that monitor and track events that could lead to oil spills or to fires and explosions.

An example from Norway concerning how BSEE could integrate real-time or archived data into a risk-based approach is given below. BSEE's recent risk-based initiatives are then reviewed, and opportunities with regard to RRTM applications in several of BSEE's existing regulations are discussed.

Norwegian Regulatory Practices

The Petroleum Safety Authority (PSA) in Norway is often cited as a regulator that uses analyses of historical data to identify the most significant hazards. Its practices provide examples of how BSEE might integrate RRTM data into a risk-based regulatory approach.[23] PSA has moved from prescriptive to more performance-based regulation (i.e., specification of the function to be performed and the performance to be achieved by the industry). PSA, like BSEE, found that prescriptive compliance inspections could encourage a passive attitude among companies, who would wait for the regulator to inspect, identify issues, and explain how

[22] For an example of a risk assessment matrix, see TRB 2008, Figure 2-5, p. 43.
[23] A more detailed discussion of the structure of PSA Norway is given by TRB 2012, pp. 58–67.

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the issues were to be addressed. Under the prescriptive approach, PSA was in some sense a guarantor that safety in the industry was adequate and assumed a responsibility that should have rested with the operating companies (PSA Norway 2010). With performance-based regulations, the responsibility for safety is explicitly that of the operator, which must ensure the safety performance of suppliers and contractors. PSA's areas of focus, such as audits, are risk-based, as determined by a broad set of data and performance indicators. Data collected through RRTM could afford BSEE a similar opportunity to supplement its risk-based inspection program, as is discussed in more detail below.

On the basis of dialogue and collaboration among industry, PSA authorities, and the workforce, major risks with regard to petroleum activity are identified and documented in an annual report known as the Risikonivå i norsk petroleumsvirksomhet (RNNP). The RNNP has an important position in the Norwegian industry because it contributes to a shared understanding of risk developments and risk perceptions by industry, Norwegian regulators, and the workforce. The RNNP documents the development (history) of a set of defined hazards and accident conditions (DFUs). There is a focus on mitigating DFUs in advance or reducing their consequences. Risk mitigation or the reduction of consequences is often based on exploration of RTM data. The RNNP is supported by additional data sources, such as the Daily Drilling Report System, and operating companies are required to provide information (in XML and WITSML) on drilling operations on the Norwegian Continental Shelf. With these data, PSA can analyze key information about all current operations. Similarly, BSEE could realize the value of RRTM through closer examination of archived real-time data that are supported through additional data sources, such as IADC's daily drilling report, as discussed in Chapter 2.

Norway's regulatory regime focuses on the following areas:

- **Risk.** The RNNP provides risk trends on the basis of incident indicators, barrier data, interviews with key informants, seminars, fieldwork, and questionnaire-based surveys. This allows the regulator to focus on *what* needs attention.
- **Performance-based regulation.** The operators must choose the solutions they will adopt to meet official requirements—the industry is responsible for *how* risks are mitigated.

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- **Accountability.** The operator has sole responsibility for safety. It must ensure the safety performance of suppliers and contractors and support a no-blame culture.

The RNNP report uses one or more risk indicators to measure the status of most DFUs, which are analyzed and reported each year. DFUs with a potential for causing major accidents include hazards such as the following: unignited hydrocarbon leak, ignited hydrocarbon leak, well incident or loss of well control, fire or explosion in other areas, combustible liquid, ship on collision course, drifting object, and collision with field-related vessel or facility tanker (see Figure 3-1). Many of these hazards have little to do with real-time data; however, the leading DFU category by far over the past 5 years is well incident or loss of well control. Over the same 5-year period, PSA has focused on the quality of barriers to mitigate the probability and to reduce the consequences of incidents. Thus barrier management and the bow tie concept are being used. A barrier is defined as technical, operational, and organizational elements that individually or together (*a*) reduce the possibility of occurrence of specific errors or hazards or (*b*) reduce or prevent damage if they occur. To ensure acceptable operations, PSA audits companies by using a risk-based approach. The audits are conducted by personnel—usually a team of two to eight people—from PSA with the necessary expertise and experience or from other institutions with the necessary expertise, such as external consultants or research and development organizations. The audit team inspects and discusses key documents, and the operator must demonstrate its compliance with the regulatory regime or conditions that govern its operations. Findings are posted on a website and distributed to all interested parties.

Audits use various approaches and methods adapted to the particular areas of focus. For example, SINTEF (Stiftelsen for Industriell og Teknisk Forskning), in conjunction with the oil and gas industry in Norway, has developed a method known as Crisis Intervention and Operability. It consists of a checklist with best available practices and a set of scenarios that can be explored to verify that the established systems can handle normal and unanticipated incidents.[24] As BSEE moves toward a risk-based

[24] More information appears at http://www.criop.sintef.no.

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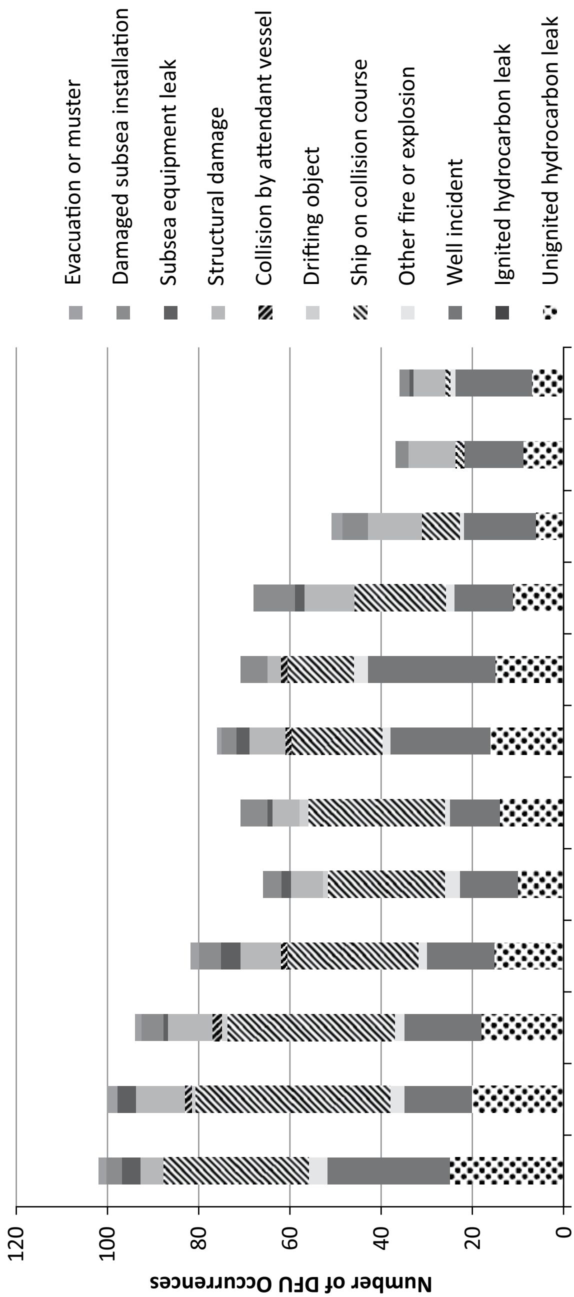

FIGURE 3-1 Reported occurrences of DFUs by category. (SOURCE: PSA Norway 2015, 17.)

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approach, Norway's experience illustrates how data collection can assist in identifying risks and could inform BSEE in many of these practices.

BSEE and Risk-Based Initiatives

As mentioned in Chapter 1, BSEE has sought to bolster its risk-based regulatory program over the past 3 years by identifying or implementing initiatives such as a near-miss and failure reporting system, risk-based inspections, and RTM of offshore facilities.[25] BSEE expects that these initiatives will help improve management of many of the risks associated with and provide additional oversight of offshore oil and gas development.

To enhance its capabilities, BSEE is pursuing a voluntary near-miss and failure reporting system[26] developed in cooperation with the U.S. Department of Transportation's Bureau of Transportation Statistics. The system will provide confidential reporting for individuals with regard to near-miss events associated with oil and gas operations. BSEE has also developed a risk-based inspection methodology—deployed within BSEE's regulatory program—that would aid BSEE in creating performance indicators to conduct further analysis and could allow the agency to prioritize which inspections and SEMS audits it should observe (DOI 2015, 8–9). Announced in December 2015, BSEE's pilot risk-based inspection program for offshore oil and gas facilities would complement the agency's existing inspections and audits to enhance the safety of offshore oil and gas operations. This approach would focus on the evaluation of risk factors related to the design, operation, and environmental characteristics of a facility that might be correlated with a higher probability of experiencing a safety-related incident.[27] The objective of a risk-based inspection program would be to use the agency's inspection capabilities in a more efficient manner.

BSEE is also reviewing the potential of RTM as a risk-based oversight technology. As discussed in Chapter 2, remote real-time data centers are in

[25] D. Morris, BSEE, presentation to the committee, December 2014; and S. Dwarnick, presentation to the committee at the Houston workshop, April 2015.

[26] More information appears at https://near-miss.bts.gov/.

[27] http://www.bsee.gov/BSEE-Newsroom/Press-Releases/2016/Bureau-of-Safety-and-Environmental-Enforcement-to-Launch-Pilot-Risk-Based-Inspection-Program-for-Offshore-Facilities/, Dec. 7, 2015.

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operation today, with some operating on a 24-hours-a-day, 7-days-a-week basis and with constant communication between the offshore platform and the onshore facility. Initially, these centers were established by industry in anticipation of efficiencies resulting from better well planning and execution and from access to expertise or other experienced personnel onshore.

As suggested by many panelists at the committee's April 2015 workshop, RRTM can enhance operational safety in several ways. Among them are supplying additional onshore monitoring of real-time data and providing offshore personnel with access to onshore expertise, especially during critical operations (TRB 2015). Although RRTM adds a substantial cost to offshore operations, companies that have implemented such centers indicated that the benefits that such centers provide are worth the costs. The value of RRTM arises from the additional information it provides, which gives decision makers the opportunity to change a current operating decision or to learn in order to guide a subsequent operating decision.

The value of RRTM for BSEE may also include increased efficiency for its inspection activities. The availability of monitoring information—whether in real time or archived—at an onshore site may support the review of safety-related information by BSEE inspectors before their visits to offshore facilities. Such preparation could allow for better scheduling of inspections—prioritized on the basis of risk—and could allow inspectors to focus on riskier operations during the visits. The value of the archived data for learning does not necessarily depend on a remote link onshore for real-time data monitoring.

RRTM and Existing Regulations

Application for Permit to Drill

Before it drills a new well, an operator must submit an Application for Permit to Drill (APD). The APD[28] (Form BSEE-0123) and the supplemental APD (Form BSEE-0123S) require information (see §250.1617 for a complete list) concerning the planned safety and environmental

[28] BSEE Form BSEE-0123 is available at http://www.bsee.gov/uploadedFiles/BSEE/About_BSEE/Procurement_Business_Opportunities/BSEE_OCS_Operation_Forms/Form0123%20exp%202017%20for%20APD%20IC.pdf.

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protection features of the new well. The proposed safety features may depend on the perceived risks of drilling and operating the new well or wells. The permitting process involves a BSEE review of the submitted documents and information and includes a dialogue between the applicant and agency personnel before BSEE approval can be given. During this process, BSEE can judge whether the plan is deficient and request the submission of additional information, if necessary.

The APD form (BSEE-0123) could be modified to include a new question about the monitoring of well parameters and well control equipment. Such a question about well monitoring would be related to performance and would allow the applicant to propose relevant uses of RRTM and to explain why the company is or is not using RRTM. It would also allow BSEE to challenge the applicant's APD with regard to the use of RRTM and the specific operations and parameters that will be monitored. Such a scenario is plausible since BSEE-0123 was modified in 2014 to add a question relating to digital BOP testing.

Safety and Environmental Management System

Adopted in 2010 as a risk-based safety management system, BSEE's SEMS plan is required to be submitted by all outer continental shelf (OCS) operators to ensure compliance with this program. SEMS is designed to be flexible, which would allow operators working in diverse OCS environments to address hazards differently on the basis of the perceived level of risk associated with an operation. The current SEMS regulations could be used by BSEE to encourage offshore operators to address the role of RRTM in their SEMS plans by allowing operators to determine the circumstances under which RRTM would be used. For example, the SEMS plan could describe the RRTM facility and the communication protocols to be used. If RRTM is incorporated into an operator's SEMS plan, BSEE inspectors could use the plan as a baseline to monitor these activities and to ensure that the operator carries out the plan consistently according to the SEMS specifications.

A review of the SEMS Potential Incident of Noncompliance (PINC) List[29] indicates that BSEE would have opportunities to consider RRTM

[29] A complete list of SEMS PINCs is available at http://www.bsee.gov/uploadedFiles/BSEE/Enforcement/Inspection_Programs/SEMS%20PINC%20List.pdf.

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applications that might allow enhanced worker safety, environmental safety, and the conservation of resources in the SEMS. For example, PINC S-202 reads as follows:

> ***Does the mechanical and facilities design information include as appropriate the P&ID [piping and instrumentation] diagram, electrical area classifications, equipment arrangement drawings, design basis for the relief system, description for the alarm system, description of the shutdown system, the interlock systems for fired equipment, well control systems, passive and active fire protection system, emergency evacuation procedures, and the cathodic system for corrosion issues?***
>
> **Authority: API [American Petroleum Institute] RP [Recommended Practice] 75 SECTION 2.3.1 Enforcement Action: W/C/S [warning/component shut-in/facility shut-in]**
>
> **30 CFR 250.1916**
>
> **INSPECTION PROCEDURE:**
> Verify that the SEMS program has been developed and maintained, and includes written procedures that provide instructions to ensure the mechanical integrity and safe operation of equipment through inspection, testing, and quality assurance.

The implementation of RRTM capability on the offshore facility, as documented in the SEMS plan, could enhance well control. Since no SEMS plan is appropriate for all facilities, this issue could be a topic of discussion between BSEE and an operator for operations in complex environments. If the SEMS plan did not include RRTM capabilities for a complex environment, an operator would need to demonstrate that the plan met acceptable standards for well control capabilities without RRTM. The committee is not suggesting that RRTM capabilities would be considered a substitute for other system safety features, but instead that RRTM would be one of many safety features.

Another PINC from this list could encourage a dialogue about risk management in the SEMS plan and could involve a review of an operator's RTM and RRTM capabilities. PINC S-200 addresses hazard identification:

> ***Does the SEMS program require that a hazards analysis be performed for the facility in order to identify and evaluate the likelihood and consequences of uncontrolled releases and other safety or environmental incidents?***
>
> **Authority: API RP 75 SECTION 3.1 Enforcement Action: W**
>
> **30 CFR 250.1911, 1911(a)**

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INSPECTION PROCEDURE:
Verify that the management program requires that a hazards analysis be performed for any facility subject to this recommended practice and that human factors are considered in the analysis.

The committee anticipates that many of these hazards would be evaluated with a matrix-based risk assessment as described earlier. Subsequently, PINCs, such as S-402 below, could focus on corresponding risk mitigation actions that might be enhanced by the use of RRTM.

Have the findings of a current (initial or periodic) hazards analysis been presented in a written report that describes the hazards identified and the recommended mitigation actions?

Authority: API RP 75 SECTION 3.6 Enforcement Action: W

30 CFR 250.1911(a)

INSPECTION PROCEDURE:
Verify that the lessee has identified the findings of a hazards analysis in a written report and that they have identified the recommended mitigating actions taken to correct the deficiency.

In addition, contractor capability and selection are important to the overall safety of OCS operations, as emphasized in PINC S-703.

Does the SEMS program document contractor selection criteria?

Authority: API RP 75 SECTION 6 Enforcement Action: W

30 CFR 250.1914

INSPECTION PROCEDURE:
Verify that when selecting contractors, operators should obtain and evaluate information regarding a contractor's safety and environmental management policies, practices, and past performance along with their procedures for selecting sub-contractors.

This aspect of the SEMS plan could be used to review the RTM data collection capabilities of a contractor, as well as the potential communication links between the contractor and the operator.

In the same spirit, PINCs S-900 and S-901 address the quality and mechanical integrity of critical equipment issues related to design, installation, inspection, and testing. A risk-based evaluation of the SEMS plan in these areas could include plans for monitoring of critical equipment

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that could depend on RTM or on RRTM to meet safety and environmental goals. The committee reaffirms that any risk management plan is an active document that requires continuous monitoring, reassessment, and reaction.

POTENTIAL OF CBM AND RRTM

As stated earlier in this report, CBM, also known as predictive maintenance, is an approach to scheduling maintenance actions that are based on the condition (measured or predicted) of the component being maintained, as opposed to replacing a component at a scheduled time or time interval regardless of the actual condition. The following section discusses opportunities for the oil and gas industry to move from interval-based maintenance of critical safety equipment to a CBM model.

Opportunities for Automation

In a 2012 paper, GE described its corporate strategy of implementing the concept of an industrial Internet delivered in three progressively higher stages of intelligence: intelligent devices (where data on the condition of the various components making up a system are collected), intelligent systems (which can be in the form of an optimized network or optimized maintenance based on the collected component data), and intelligent decisioning (which occurs when "enough information has been collected from the devices and systems to facilitate data-driven learning, which in turn enables a subset of machine and network-level operational functions to be transferred from operators to secure digital systems") (Evans and Annunziata 2012, 12). GE has proposed to develop this concept and apply it to a number of the sectors in which the company provides devices, systems, and services, such as aviation, health care, and oil and gas production. For example, Iansiti and Lakhani (2014) state that by

> 2011, along with sensors and microprocessors, GE had significant embedded software running power plants, jet engines, hospitals and medical systems, utility companies, oil rigs, rail and other industrial infrastructure worldwide. Connecting the hundreds of thousands of GE devices to one another and arming them with increasingly sophisticated sensors seemed like a logical extension of the maintenance-and-operations model.

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Before the intelligent decisioning functionality (i.e., significant automation) can be envisioned, the intelligent device functionality (i.e., CBM) must be delivered. The potential for CBM clearly exists, and progress is being made in some sectors such as transportation, but even this sector is still in the early stages of broad implementation of CBM based on predictive models. Aviation norms, procedures, and maintenance philosophy are rooted in time-tested, interval-based maintenance. Most mission- and safety-critical industries, including the oil and gas industry, operate on time-based or interval-based maintenance models. To move toward CBM, a dense set of data must be collected and accessed from the equipment to be maintained, which is well beyond the state of practice in the oil and gas industry. A move toward CBM would require investments during equipment design and MODU construction. To deliver effective performance baselining, a dense data set with high standards of data quality is needed from the beginning of service for a piece of equipment. To achieve system-level CBM, several generations of equipment will need to be designed and delivered into service, which could take up to a decade. Equipment and process monitoring from onshore centers has already taken root in the industry, and onshore monitoring centers could serve as an early step toward achieving true system-level CBM. The data collected from equipment and monitored from these onshore centers are operational in nature and may not be useful for CBM. Retrofitting of current equipment to collect condition data is an important intermediate step toward true CBM. Given the variation of equipment (e.g., rotating, nonrotating) and industry's reliance on fit-for-purpose engineering (e.g., no two MODUs are identical), achieving system-level CBM will prove challenging and time-intensive. However, component-level CBM for risers, on-deck rotating equipment, BOPs, and pumps are all promising candidates for early adoption.[30]

Industry may not be able to achieve equipment CBM sooner because of a combination of three factors: lack of skills and expertise in applying CBM approaches, data access and data richness or quality challenges

[30] Diamond Offshore and GE Oil and Gas entered into an arrangement similar to a performance-based or uptime model, under which GE takes ownership of the BOP and is accountable for its performance. See http://www.oedigital.com/component/k2/item/11571-diamond-ge-ink-performance-based-bop-deal.

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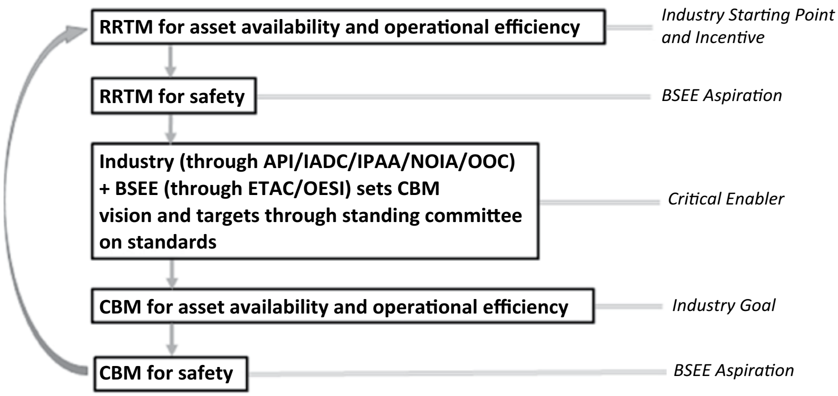

FIGURE 3-2 **Developing CBM through RRTM** (ETAC = Engineering Technology Assessment Center; IPAA = Independent Petroleum Association of America; NOIA = National Ocean Industries Association). (SOURCE: Generated by the committee.)

(Terranova 2015), and maintenance norms (i.e., method and philosophy). However, an opportunity exists for advancing CBM approaches in the oil and gas industry through incentives and collaboration. The data collected from such initiatives as remote inspection of equipment could be used to verify recommendations arising from CBM. (See Figure 3-2.)

Even if equipment- and system-level CBM can be delivered, achieving intelligent decisioning or automation in the offshore context will present additional challenges. Among them are delivering data access (transmission, security, richness, and quality), defining response options to detected fault conditions, and achieving situational awareness. Delivering reliable automated decision support will also entail more testing cycles.

Potential Predictive Software Issues

Predictive software and data analytics have already reached levels capable of achieving CBM in other sectors—for example, aircraft and locomotive engines and wind turbines.[31] However, the mission-critical equipment involved in offshore oil and gas operations is often engineered fit for

[31] For examples of CBM in other sectors, see http://www.fastcompany.com/3031272/can-jeff-immelt-really-make-the-world-1-better.

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purpose. Thus, each company's equipment has its own engineering and manufacturing backgrounds. This implies a need for detailed information about and understanding of the equipment's intended behavior to determine correlations with the data collected. For prediction of impending conditions, as opposed to recognition of the existence of a condition, higher-fidelity data capture is often required to build signature libraries of condition precursors by using acoustic, vibration, or other significant parameters. Higher-fidelity data capture will need to be considered during the equipment design cycle (e.g., for sensor placement) and during testing cycles (e.g., for the building of signatures).

Predictive software–based modeling (correlation analysis, data computation, and algorithm development) is strongly dependent on designing CBM into the entire product plan and life cycle. CBM will require sophisticated sensors and sophisticated testing to determine ideal sensor location for detecting the signatures of condition precursors.

In addition, the following issues will need to be considered during all phases of the equipment life cycle if industry is to perform predictive maintenance:

- Practice of a high level of data hygiene throughout the equipment's lifetime, which could be 30 to 40 years;
- Continuous (or thick) data, such as vibrations, which tax data networks much more than discrete data, such as temperature, oil pressure, or chip count;
- Availability of data science expertise so that the latest and most appropriate data analytic approaches can be applied;
- Better baselining for equipment time in field and cycle counts;
- Collection and stewardship of detailed asset management life-cycle records; and
- Recertification of equipment, in the case of retrofitting, which often can be provided only by the OEM.

Potential Hardware Issues

To deliver CBM for the oil and gas industry's equipment, a number of hardware issues will need to be addressed. Because many pieces of equipment may be inaccessible and in a harsh environment, they will need the ability to self-calibrate and operate at high temperatures and pressures,

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and they will need to demonstrate a track record as in other industries with similar conditions. With an increase in the number of testing cycles and the baselining of equipment, more data will need to be captured, stored, and managed over the life cycle of the asset, which has implications for the data storage capabilities designed into the equipment. To achieve system-level CBM capability on the MODU, a complete history of the condition of each piece of mission-critical equipment will need to be collected and maintained. This is known as a digital twin. The test facilities for this equipment, along with the sensing and data collection hardware, will need to simulate the real-world conditions in which they operate more closely. The costs of the design and testing of this equipment will likely need to be shared among OEMs and exploration and production companies. Finally, enhanced inspection capabilities will be needed to verify what the integrated sensors report.

Model-Based Workflows

Drilling and production operations are complex and require extensive planning. The challenge for many operators and service companies is executing a drilling or production plan while retaining the flexibility to respond to unanticipated conditions. In addition, interoperability of all actors and processes is critical. Enhanced data and new technology developments are increasing the availability of model-based workflows.

Analytics to help in decision making are another interesting area of technology development. Smart algorithms, case-based reasoning techniques, machine learning algorithms, and science-based modeling processing flows all are bringing data-driven aids to decision makers, both offshore and onshore. Most of these solutions are still at the early stage of development and evaluation, and few operators will depend on automated decision making, except for safety-based processes. Decision-making responsibility still lies in the hands of experienced staff, mostly located offshore.

SUMMARY DISCUSSION

This chapter examined the implementation of RRTM technology in the context of BAST and suggests that RRTM could become widely available to industry and a part of its tool kit. The committee is not suggesting that

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RRTM be mandated on all wells, but instead that the implementation of RRTM as BAST could be considered relative to its potential contributions to overall safety, consistent with the principle of ALARP, where practicability is interpreted as encompassing both technological availability and economic feasibility.

The chapter provides four examples of the notional benefits of applying RRTM in the areas of well integrity and early kick detection, augmented competencies from onshore, BSEE regulatory oversight and inspections, and CBM of critical equipment. With the increased availability of real-time data to onshore facilities, onshore crews can provide more assistance in monitoring real-time data. As companies establish roles and responsibilities and develop communication protocols, RRTM allows additional onshore staff to support offshore decision making and provides quick access to and collaboration with onshore expertise. BSEE is in a position to leverage archived RRTM data to support the more risk-based regulatory program that it has adopted. Deploying a greater array of sensors and enabling the aggregation of the generated data from equipment and assets across the entire fleet are both important for CBM. RRTM is effective in enabling the transfer of offshore data to onshore facilities and in allowing empirical data to be used in predictive modeling and, ultimately, CBM.

As sensor technology advances and as the ability to transmit that data improves, data management issues involved with the use of real-time data will likely become more important. Increased use of RRTM of offshore operations and equipment will place new demands on the instrumentation of drilling and production equipment. Control systems for mission-critical rig-based equipment were not originally designed for connectivity back to Internet-facing systems and are not necessarily designed to be resilient to computer-based incidents that could corrupt or alter software. As more RRTM of offshore operations is introduced, the cybersecurity risks associated with the increased use of technology will rise.

RRTM could benefit BSEE in some of its inspection activities by offering increased efficiency. Monitoring information—whether in real time or archived—could support the review of some safety-related information by BSEE inspectors before their visits to offshore facilities. Preparation could allow for more efficient scheduling and more effective execution of inspections, which would be prioritized on the basis of risk.

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BSEE could use existing regulations, such as SEMS, to manage the use of RRTM. By encouraging offshore operators to address the role of RRTM in their SEMS plans, BSEE could allow operators to determine the circumstances under which RRTM would be used.

Operational data collected from much of the equipment and currently monitored by onshore centers may not be useful for CBM, although collection of more conditional data is a first step. To move toward CBM, a dense set of data must be collected and accessed from the equipment or asset to be maintained, which may be beyond the current state of practice in the oil and gas industry and not attainable in the short term. Predictive software–based modeling of equipment will require sophisticated sensors and testing to determine ideal sensor locations for detecting the signatures of condition precursors. More data will need to be captured, stored, and managed over the equipment's life cycle. Hardware issues also will need to be addressed, since equipment may be inaccessible and in a harsh environment.

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Abbreviations

ABS	American Bureau of Shipping
BSEE	Bureau of Safety and Environmental Enforcement
DNV GL	Det Norske Veritas and Germanischer Lloyd
DOI	U.S. Department of the Interior
NAE	National Academy of Engineering
NRC	National Research Council
OGP	International Association of Oil and Gas Producers
OLF	Oljeindustriens Landsforening (Norwegian Oil Industry Association)
PSA	Petroleum Safety Authority
TRB	Transportation Research Board

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4

Findings and Recommendations

The committee's charge was to advise the Bureau of Safety and Environmental Enforcement (BSEE), U.S. Department of the Interior, on the use of remote real-time monitoring (RRTM) systems by industry and government to improve the safety and reduce the environmental risks of offshore oil and gas operations. As a central part of its remit, the committee held a public workshop, which has guided the findings and recommendations presented in this final report. Specifically, the committee's workshop and final report were to address the critical operations and parameters to be monitored, the role of automation and predictive software, the role of condition-based maintenance (CBM) in RRTM, whether RRTM should be incorporated in BSEE's regulatory scheme, and how BSEE should leverage RRTM to enhance its safety enforcement program.

Chapter 2 outlined the nature of offshore oil and gas operations and discussed industry experience with RRTM systems and their application in the monitoring of drilling and production operations. The chapter also briefly discussed two previous reports concerning RRTM and reviewed the committee's April 2015 workshop summary report.

Chapter 3 briefly examined best available and safest technology (BAST) as it relates to RRTM. The chapter discussed the benefits of RRTM in the oil and gas industry on the basis of four use cases. Considerations and challenges concerning the application of RRTM to the delivery of these use cases were presented. Issues discussed included data management, cybersecurity, the role of RRTM in risk-based regulations, and the potential of using real-time data for CBM. The committee's consensus findings and recommendations are presented below.

Finding 1. The use of RRTM is highly variable across the offshore oil and gas industry. No industry standard or standard practice for the

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implementation of RRTM exists, and the industry exhibits varying levels of maturity in its use of RRTM. Operators using RRTM believe that it offers benefits related to increased efficiency, reduced downtime and operational disruptions, reduced equipment damage, increased safety, and overall reduction in risk.

Operating companies justify the use of RRTM on the basis of a business need, which can include aspects of safety, and that need can differ among companies. There is no uniform solution ("one size does not fit all") for RRTM implementation because there is no uniformity in many aspects of offshore oil and gas operations. The committee notes that the management of offshore operations varies by the type of operator—major, large independent, small independent—and that drilling operations and production operations present different risks. Drilling and production operations also differ in scope and scale, which further complicates any proposed regulatory approach to RRTM. Offshore facilities vary in location, water depth, size, age, design, and breadth of operations. Safety may be the initial impetus for implementing RRTM, but increased efficiency and operational reliability can also result. While there are no industrywide RRTM best practices or standards, the committee notes that companies using RRTM monitor some of the same critical operations and parameters as those listed in the internal BSEE report (BSEE 2014) and the 838, Inc., report (2014). Many of those operations and parameters were presented to the committee at its first meeting and at its subsequent workshop.

Finding 2. The committee's workshop and discussions with industry indicate that responsibility and accountability for offshore operations reside with the lessee as designated by BSEE when the lease assignment is made. Representatives of the U.S. oil and gas industry uniformly expressed a strong belief that the responsibility and authority for operational decision making should remain on the mobile offshore drilling unit (MODU) or other offshore facility.

RRTM can provide support to the operational decision making of offshore operations. It can offer offshore personnel access to technical support and onshore expertise. The design of any RRTM system requires industry to address the entire operational system on the MODU or other

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offshore facility. Ensuring that the proper protocols and procedures are in place is critical in supporting the operator's decision-making ability, and the decision-making realities dictated by the need for situational awareness must be considered. The committee recognizes that there are unmanned platforms and subsea developments. In such cases the decision makers are located at the nearest connected, manned facility, whether offshore or onshore.

Finding 3. Currently, real-time data are generated and collected on the MODU and are used by offshore personnel in making operational decisions.

Industry uses archived drilling performance data, when they are available, for planning new wells and for recreating events. A large number of sensors already exist on many MODUs and in many of the rig systems. Industry has voiced concern about data validity and reliability. Industry representatives at the committee's workshop believed that including more sensors would magnify validity and reliability problems because of the need to maintain complex sensor systems in addition to those already in place (see TRB 2015). However, properly designed networks of sensors with cross-checking algorithms could reduce the problems associated with sensor reliability.

Finding 4. In the committee's judgment, appropriate RRTM can be considered BAST. It would need to be applied in a manner consistent with the recommendations made by a recent report on implementing BAST for offshore oil and gas operations.

In this context (see Chapter 3), the implementation of RRTM would be considered relative to its potential to reduce risk and contribute to overall safety—consistent with the principle of ALARP (as low as reasonably practicable)—where practicability is interpreted as encompassing both technological capability and economic feasibility. Ultimately, the director of BSEE initiates the BAST determination process and makes the final BAST decision. However, this committee (as supported by NAE and NRC 2013, 13) considers "safest technology" to include all technologies that reduce risks and that are consistent with the principle of ALARP. Improving safety can encompass both occupational and process safety.

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At its workshop, the committee was told repeatedly that RRTM (whether done continuously or more intermittently) can offer benefits related to increased efficiency, decreased downtime and operational disruptions, reduced equipment damage, improved safety, and overall reduction in risk. RRTM is done on some wells but not on every well; each determination includes an assessment of risk. Each operator has a different business case and uses its own internal risk management process in assessing each well. Viewing RRTM as BAST does not mandate the use of RRTM on every well, and the committee does not endorse the mandatory continuous use of RRTM. RRTM is one of many technologies that industry uses to support safe operations.

Finding 5. The committee is not in a position to recommend or validate a standard definitive list of critical operations, sensors, systems, and parameters for RRTM.

Furthermore, in the committee's judgment, a single standard list for all operations is not a practical aspiration, in view of the variability in operating conditions, geology, scope and scale of facilities, the evolution of technology, consideration of human factors, and the incorporation of RRTM in a risk-based approach to regulating offshore operations. However, industry representatives that presented to the committee provided numerous examples of monitored operations (see TRB 2015). In addition, as noted above, companies using RRTM monitor some of the same critical operations and parameters as those listed in an internal BSEE report (see BSEE 2014, Annex 1, p. 14, Annex 2, p. 17, and Annex 3, p. 20) and the 838, Inc., report (2014), which enumerates data collected, monitored, or calculated (see pp. 110–124). These lists are all reasonable starting points for conversations between BSEE and industry.

Finding 6. The committee recognizes and supports the efforts of the American Petroleum Institute (API) real-time monitoring study group and encourages industry to work with the regulator to achieve short- and long-term goals related to the use of RRTM for safe offshore operations.

As reported to the committee, the use of RRTM data can positively affect operations, including safety. The committee encourages industry

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stakeholders to share best practices and lessons within and across the industry, since some experiences indicate that RRTM can improve safety in operations.

Finding 7. CBM could increase efficiency in multiple phases of offshore operations and increase the maintenance reliability of critical safety equipment, such as the blowout preventer (BOP).

The committee considers RRTM to be a necessary but not sufficient condition for achieving the longer-term benefits that would come from CBM of offshore equipment and systems. To facilitate CBM, predictive models will need to be developed by using monitored operational data—such as temperature, pressure, vibration, and fluid properties—and material fatigue analysis. These data and the models that are based on them will be crucial for any CBM endeavor, including the BOP. A longer-term goal of CBM requires that data be collected and stored continually over the lifetime of the equipment and systems. However, BOP maintenance history may be difficult to access, poorly tracked, and incomplete. Achieving CBM could be difficult in the offshore business environment given the variability, complexity, and risk inherent in different wells, facilities, and operations. Additional considerations include the economic test associated with the choice of BAST and the international movement of equipment and systems. The BOP, which is a critical piece of safety equipment for drilling operations, is expected to function in emergencies as one of the barriers to maintain well control. Maintaining and servicing BOPs during operations can be expensive and time-consuming, which provides an incentive for the development of CBM for BOP systems.

Finding 8. Specific subtasks for offshore drilling and production are automated. However, the level of automation is limited, and automation is in a research phase in most companies. The use of predictive software integral to automation is also limited due to a lack of instrumentation, which leads to a lack of relevant data and could inhibit the necessary sophistication of algorithms.

At its workshop, the committee was told that automation for certain activities such as pipe racking and power management is commonplace

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and that the rotary steerable tool at the wellsite does have some automated capability in setting a path and maintaining a heading during drilling. However, the performance of critical equipment and the work processes utilizing that equipment would need to be captured by instrumentation before they could be modeled in a computer program and ultimately automated. Accurate algorithms for performance prediction would allow the operator to have confidence in forecasts. When a process is known and consistent, it can be automated. Lack of or variable maintenance of sensors and meters gives rise to concerns about data quality and could lead to manual processes that bypass digital measurements. RRTM helps enable the collection of data and the development of better algorithms for predictive tools, but the lack of standard practices drives custom, tactical advances rather than holistic ones.

Finding 9. Cybersecurity vulnerabilities in the oil and gas industry exist and are increasing as the use of technology expands and evolves. In addition, legacy control systems were typically not designed with remote connectivity or cybersecurity in mind.

Cybersecurity guidelines are offered in both the National Institute of Standards and Technology's Cybersecurity Framework and the 62443 series of the American National Standards Institute and the International Society for Automation. The Drilling Control Systems Subcommittee of the Advanced Rig Technology Committee, International Association of Drilling Contractors (IADC), has established a Cybersecurity Work Group. The group has developed draft guidelines based on existing standards that will provide direction to industry on establishing a methodology for assessing cybersecurity risks. Reevaluating risks as RRTM systems are added to offshore drilling and production operations is an important step.

The United States Coast Guard (USCG) released its cyberstrategy in June 2015. The strategy outlines USCG's plan to work with industry and to manage cyberrisks to critical maritime infrastructure. USCG plans to release a final policy in 2016. BSEE has not released its own cyberstrategy but is collaborating with USCG. BSEE has an opportunity to engage industry stakeholders in determining the most viable route toward an industry standard for cyber-related threats to RRTM.

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Finding 10. Data collected from real-time operations can help BSEE inspectors in preparing for their on-site visits. Although it would not necessarily be part of RRTM, these data could play a role in an improved document and information management process for BSEE.

As long as regulations require periodic inspections of each offshore facility, BSEE may have difficulty in reducing the number of its on-site visits. Operators presenting at the committee's workshop will accept visits by BSEE inspectors to their RRTM centers (when they exist), but they do not want these visits to replace offshore inspections (see TRB 2015). As suggested at the committee's April 2015 workshop, remote monitoring of the frequent tests of BOPs could be a starting point and serve the interests of equipment manufacturers, service companies, operators, and the regulator.

The lack of standardization of RRTM solutions could hinder inspectors in making good use of these data before their offshore visits and in utilizing RRTM as a replacement for inspections. The internal BSEE report (2014) discusses the need for properly trained personnel[1] and illustrates how digital information can help in inspector preparation—and thus improve the efficiency and effectiveness of each visit—but, in the committee's judgment, RRTM per se may not cut down on the number of visits. The use of historical RRTM data could support the development of a risk-based inspection policy that is being piloted by BSEE by providing inspectors with a data-driven knowledge of performance. The committee was told by industry representatives at its workshop that RRTM does not replace the ultimate accountability of the operator for safe operations on the offshore facility. Furthermore, in the committee's judgment (and as acknowledged by the BSEE report authors), many of the ideas set forth for RRTM in BSEE's internal report are not achievable for several reasons, such as staffing, legal and regulatory environments, and the level of current and future technology. In particular, the development of a BSEE RRTM center for the Gulf of Mexico is not warranted, nor would such a center be effective at this time.

[1] See also Chapter 3 of 838, Inc. 2014.

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Recommendation 1. BSEE should pursue a more performance-based regulatory framework by focusing on a risk-based regime that allows industry to determine relevant uses of RRTM on the basis of assessed levels of risk and complexity.

Although the industry maintains responsibility for gathering and responding to operational real-time data, BSEE could challenge operators to discuss the RRTM of complex (risk-ranked) wells and critical production facilities in their Application for Permit to Drill and in their Deepwater Operations Plan. Safety and Environmental Management Systems (SEMS) guidelines require the identification and mitigation of risks in outer continental shelf (OCS) operations. BSEE could also challenge operators to include an RRTM plan in their SEMS document. BSEE could ask industry to include test procedures, plans, and other information. BSEE could use these items to review execution of the plan by visiting operation centers to determine whether an operator is following its own RRTM plan.

Furthermore, because SEMS plans require the identification and mitigation of risks in OCS operations, the potential exists for SEMS planning to include cyber-related threat mitigation.[2] In this context, BSEE could also work with industry stakeholders to provide additional guidance on how well these cyberrisks are mitigated on a systematic basis by incorporating cyberrisk management through SEMS. Any regulatory framework should allow a phase-in period that gives operators and contractors time to comply.

Recommendation 2. The committee views RRTM as BAST when justified by the risk of particular wells. **BSEE should monitor the spectrum of RRTM technologies and best practices by using either an internal BSEE group, such as the agency's proposed Engineering Technology Assessment Center (ETAC), or an external organization, such as the Ocean Energy Safety Institute (OESI).**

[2] See comments by Rear Admiral Paul Thomas at the 2015 Offshore Technology Conference concerning management of the risk of cybersecurity issues through a safety management system (http://mariners.coastguard.dodlive.mil/2015/05/21/5212015-2015-offshore-technology-conference-complexity-of-operations-and-cyber/).

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The suitability of RRTM for specific wells and facilities should be judged in a manner consistent with the recommendations made by a recent report on implementing BAST for offshore oil and gas operations (NAE and NRC 2013). Criteria would include both the technical availability and the economic feasibility of any proposed technologies and would allow operators to judge the value of RRTM in the context of ALARP. Monitoring RRTM technologies would allow BSEE to enhance its safety management program and is more consistent with a performance-based regulatory framework.

Recommendation 3. Consistent with recommendations of previous committees of the National Academies (NAE and NRC 2012; NAE and NRC 2013), **BSEE should encourage involvement of all stakeholders in the development of risk-based goals and standards governing offshore oil and gas processes. Specifically, BSEE should work with API, IADC, and other relevant stakeholders to form an API standing technical committee (as opposed to an ad hoc committee) that would establish minimum requirements for which critical operations (and parameters) are monitored and for which data are collected and monitored in real time. In addition, BSEE, along with this technical committee, should propose standards for communication protocols between onshore and offshore facilities when RRTM is used.**

As noted in Finding 5, the committee is not in a position to recommend or validate a standard definitive list of critical operations and parameters and does not believe that such a list for RRTM is practical in view of the variability of operational environments and the impact of changing technology. However, industry has the breadth of RRTM experience in both drilling and production environments needed to establish minimum data set requirements. Experience with RRTM will grow as more industry stakeholders adopt the technology. All industry stakeholders should collaborate through an API technical committee to establish and keep up to date a minimum set of data that could be monitored and stored as more operators utilize RRTM. Ultimately, this minimum data set could be the basis for industry-recommended practices or standards for the application of RRTM. This API committee could also document how RRTM can serve as an effective risk management

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tool and demonstrate RRTM's value through risk reduction, increased efficiencies, and improved safety.

The committee believes that BSEE should be represented on this API technical committee, and it strongly encourages industry to move toward collecting all relevant and appropriate data. In the committee's opinion, in deciding what and how much data are to be collected, industry should consider the data's use in potential applications, such as CBM. Collection of RRTM data is necessary for achieving the longer-term benefits that would come from CBM of equipment and systems. This longer-term goal would require that the collected data be stored over the lifetime of the equipment and systems. Although such a goal could be difficult to achieve in view of the operational realities of offshore drilling (e.g., international rig movements), CBM should be considered a priority for critical safety equipment, such as BOPs.

In addition, as noted in Chapters 2 and 3, explicit protocols must govern the interactions between offshore operating staff and the remote center, whether they concern a discussion initiated from offshore or how escalation will occur when anomalies are detected from an onshore RRTM center. BSEE's internal report acknowledges this point by noting that effective communication between offshore and onshore staff demands clear protocols and procedures on identifying, verifying, and escalating safety concerns and that guidance must be provided on who should talk with whom (BSEE 2014). For current operators of RRTM centers, the design of communication protocols is carefully thought out, and within each company these protocols are documented and followed when issues arise. However, across the industry, operators have different protocols, and standardization between companies does not appear to exist. As suggested by panelists at the committee's workshop, BSEE can take a leading role in providing guidelines on communication protocols (TRB 2015).

Recommendation 4. BSEE should encourage API to work with original equipment manufacturers (OEMs), drilling contractors, and industry trade associations to establish a BOP CBM pilot project, with the goal of an API publication.

The pilot project should be phased in and should include multiple sensors that report the same or similar data. The work—monitored by

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BSEE—could be done in cooperation with ETAC or OESI. BOPs are a critical piece of safety equipment located either at the surface or on the seafloor for all MODUs. Surface BOPs are readily accessible and can be inspected and repaired or maintained in place or at a rig work area. CBM sensors can be accessed relatively easily and can be connected or replaced efficiently. Subsea BOPs are run in place (in water depths up to 12,000 feet) and remain there through the drilling process unless they need to be repaired. Pulling and rerunning the BOP can take several days, and therefore any repairs, sensor replacement, or other work on a subsea BOP is more time-consuming. This creates an incentive for developing CBM capabilities so that issues can be detected and the pulling operation better planned. Work to create this CBM pilot should be led by an established industry committee such as the API Standards Committee. It should include OEM BOP and CBM personnel, drilling contractor personnel with expertise in BOPs and CBM, operating company personnel with drilling expertise, and trade associations with interest in this issue (such as IADC, the Petroleum Equipment Supplier Association, and the Offshore Operators Committee). For CBM to be effective and to be applicable beyond a pilot test, an industry publication such as an API standard should be developed.

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Abbreviations

BSEE	Bureau of Safety and Environmental Enforcement
NAE	National Academy of Engineering
NRC	National Research Council
TRB	Transportation Research Board

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APPENDIX A

Notice of Proposed Rulemaking Concerning Relevant Real-Time Monitoring Provisions in the Proposed Arctic Rule

Notice of Proposed Rulemaking:
Relevant Real-Time Monitoring Provisions in the Proposed Arctic Rule (released February 24, 2015; source: https://federalregister.gov/a/2015-03609)

§250.452 What are the real-time monitoring requirements for Arctic OCS exploratory drilling operations?

(a) When conducting exploratory drilling operations on the Arctic OCS, you must have real-time data gathering and monitoring capability to record, store, and transmit data regarding all aspects of:
   (1) The BOP control system;
   (2) The well's fluid handling systems on the rig; and
   (3) The well's downhole conditions as monitored by a downhole sensing system, when such a system is installed.

(b) During well operations, you must immediately transmit the data identified in paragraph (a) of this section to a designated onshore location where it must be stored and monitored by qualified personnel who have the capability for continuous contact with rig personnel and who have the authority, in consultation with rig personnel, to initiate any necessary action in response to abnormal data or events. Prior to well operations, you must notify BSEE where the data will be monitored during those operations, and you must make the data available to BSEE, including in real time, upon request. After well operations, you must store the data at a designated location for recordkeeping purposes as required in §§ 250.466 and 250.467.

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APPENDIX B

Notice of Proposed Rulemaking Concerning Relevant Real-Time Monitoring Provisions in the Proposed Blowout Preventer Rule

Note: During the final stage of the National Academies report review process, the Bureau of Safety and Environmental Enforcement released its final Blowout Preventer Systems and Well Control rule. Given the timing of the release, the committee was unable to include additional information about this rule in its final report. The final rule is available at https://www.gpo.gov/fdsys/pkg/FR-2016-04-29/pdf/2016-08921.pdf.

Notice of Proposed Rulemaking:

Relevant Real-Time Monitoring Provisions in the Proposed BOP Rule (released April 17, 2015; source: https://federalregister.gov/a/2015-08587)

§ 250.724 What are the real-time monitoring requirements?

(a) When conducting well operations with a subsea BOP or surface BOP on a floating facility or when operating in an HPHT [high-pressure, high-temperature] environment you must, within 3 years of publication of the final rule, gather and monitor real-time well data using an independent, automatic, and continuous monitoring system capable of recording, storing, and transmitting all aspects of:
    (1) The BOP control system;
    (2) The well's fluid handling systems on the rig; and
    (3) The well's downhole conditions with the bottom hole assembly tools (if any tools are installed).

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(b) You must immediately transmit these data as they are gathered to a designated onshore location during operations where they must be monitored by qualified personnel who must be in continuous contact with rig personnel during operations. After operations, you must preserve and store this data at a designated location for record-keeping purposes as required in §§ 250.740 and 250.741. You must designate the location where the data will be stored and monitored during operations in your APD [Application for Permit to Drill] or APM [Application for Permit to Modify]. The location and the data must be made accessible to BSEE upon request.

(c) If you lose any real-time monitoring capability during operations covered by this section, you must immediately notify the District Manager. The District Manager may require other measures until real-time monitoring capability is restored.

Records and Reporting

§ 250.740 What records must I keep?

You must keep a daily report consisting of complete, legible, and accurate records for each well. You must keep records onsite while well operations continue. After completion of operations, you must keep all operation and other well records for the time periods shown in § 250.741 at a location of your choice, except as required in § 250.746. The records must contain complete information on all of the following:

(a) Well operations, all testing conducted, and any real-time monitoring data;
(b) Descriptions of formations penetrated;
(c) Content and character of oil, gas, water, and other mineral deposits in each formation;
(d) Kind, weight, size, grade, and setting depth of casing;
(e) All well logs and surveys run in the wellbore;
(f) Any significant malfunction or problem; and
(g) All other information required by the District Manager.

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§ 250.741 How long must I keep records?

You must keep records for the time periods shown in the following table.

You must keep records relating to:

(a) Drilling; until 90 days after you complete operations.
(b) Casing and liner pressure tests, diverter tests, BOP tests, and real-time monitoring data; until 2 years after the completion of operations.
(c) Completion of a well or of any workover activity that materially alters the completion configuration or affects a hydrocarbon-bearing zone; until you permanently plug and abandon the well or until you assign the lease and forward the records to the assignee.

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APPENDIX C

Potential Barriers Related to Data Transfers and Communication Alternatives

Communication Element	Definition	Key Issues
Bandwidth	Bandwidth refers to data rate transfer, or the amount of data that can be carried from one point to another in a given time period, and is usually expressed in bits per second (bps).	Modern offshore facilities require higher bandwidths. Bandwidth requirements will continue to increase as offshore facilities add requirements for real-time data sharing or videoconferencing. Different communication applications require different bandwidths. For example, instant messaging uses less than 1,000 bps, while high-definition video requires up to 4 Mbps.
Latency	Latency in communications often refers to the delay (or wait) between a source sending data and the destination receiving the data. This wait time can vary from one system to another. The delay is often introduced when the data travel over the geographical distance and different types of communications equipment.	Latency can be critical for applications connected by either satellite or microwave networks and could limit technologies for real-time monitoring applications. Sources of latency can include propagation, transmission, and router and end-user issues.
Synchronization	Synchronization for communications refers to the relationship of data from multiple sources with the actual time of occurrence.	Data can be generated and gathered from different types of sensors and processing equipment. Careful synchronization of the time stamps of data elements is necessary for the correct interpretation of collected data.

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Communication Element	Definition	Key Issues
Reliability, performance, and affordability	Reliability, performance, and affordability refer to the challenges of designing a network that will provide the necessary support for the movement of data at a specified capacity, speed, and cost.	Designing a reliable, high-performance network in remote and often harsh environments might prove costly to many companies. Given this type of environment, the shorter-term contractual arrangements of drilling operations could lead to a network solution that is assembled from multiple providers. Such hybrid solutions supported by multiple oil service companies could create less reliable network designs. Production facilities allow for a more permanent and integrated communications solution. Redundancy of systems is important for minimizing downtime of critical data transmission that may occur during common communication outages and planned maintenance.

NOTE: Mbps = megabits per second.
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APPENDIX D

Telecommunications Options for Offshore Drilling and Production Operations for Connections to Onshore Headquarters Support Centers

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Technology Option	Bandwidth Range	Standard Communication Link[a]	Drilling[b]	Production[c]	Videoconferencing[d]
Requirements	The standard bandwidth for an offshore platform is 5 to 10 Mbps but is projected to rise to 20 Mbps. If demand for video communications from offshore installations increases, required bandwidth could rise to 100 Mbps.	Instant messaging takes less than 1 Kbps, while a VoIP call requires 56 Kbps.	Drilling tools are capable of taking directional surveys and transmitting data to the surface in real time; the location of the wellbore can be calculated by using measurements of inclination, azimuth, and tool face. Similarly, drilling tools can take measurements of formation properties after data are sent to the surface and assembled into a log. Data transmission rates will depend on the approach used.	SCADA systems have been in operation for years and can usually be migrated to high-speed networks and open nonproprietary protocols with planning and study of available options. Systems designers must be familiar with issues of functionality, transmission delays, polling cycles, data processing requirements, and available technologies. In addition, proprietary and vendor-specific protocols and programs should be avoided at all costs in lieu of open standards and easily interchangeable software and hardware from one vendor to another. For DTS, a fiber-optic cable can be used both as sensor and for communications at very high transmission speeds.	Standard-definition video works at 1 Mbps, but HD video requires 4 Mbps and HDX needs more than 7 Mbps; usual total bandwidth requirement for all applications on a drilling rig is 2 to 4 Mbps.

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Microwave	Microwave can range from 512 Kbps to 5 Mbps, depending on the communications path. Microwave is limited by line-of-sight links, and hops are usually limited to about 20 miles until a repeater station is needed in the network.	Yes	Through the use of microwave telecommunications technology, data are transported via wavelengths that measure less than 1 meter. Microwave communications solutions offer more bandwidth for data but are restricted to shorter distances because of signal attenuation.	Microwave telecommunications are often chosen for locations that are near each other, such as a cluster of facilities on a field.	Usually not capable of handling video sessions over the long distances to a shorebase or onshore operations center.
Satellite	Commercial satellite Internet bandwidth can range from 200 MB per day to 25 GB per month. A shared download carrier may have a bit rate of 1 to 40 Mbps, to be shared by 100 to 4,000 end users. The highest-capacity communications satellite has a total throughput capacity of 140 Gbps for all users.	Yes	The most widely chosen solution for offshore communications, satellite communications require a VSAT at the offshore site, a broadband satellite connection in space, and a teleport onshore. Available anywhere in the world, satellite services are used many times for vessels that may be on the move or for extremely remote locations.	Yes, but in several operating regions (North Sea, Gulf of Mexico, Gulf of Thailand, northwest coast of Australia) of the world, fiber-optic cables offer an alternative for fixed platforms.	Only basic capability unless operator invests the money to upgrade services; issues of latency and sharing bandwidth with real-time applications must be considered.

(continued on next page)

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Technology Option	Bandwidth Range	Standard Communication Link[a]	Drilling[b]	Production[c]	Videoconferencing[d]
Fiber	Fiber-optic networks operate under standards such as 10Base-F, 100Base-F, FDDI, 1,000Base-F, and 10Gbase and include bandwidth capacity in their definitions—from 10 Mbps to 10 Gbps.	Yes	Drilling rigs are usually in remote locations where getting fiber to the rig is expensive. Although it is limited because cables must be run from point to point, fiber is an optimal communications solution for clustered facilities or offshore locations that are in high-traffic areas, such as the North Sea or the U.S. Gulf of Mexico. Also, fiber cables are used to transmit data between subsea trees, manifolds, jumpers, sleds, and controls via umbilicals.	Yes, and use of this option is increasing in some operating areas. Often fiber can be laid for internal field operations, but VSAT must be used to connect to shorebase.	Yes

NOTE: Mbps = megabits per second; Kbps = kilobits per second; VoIP = voice over Internet protocol; SCADA = supervisory control and data acquisition; DTS = distributed temperature surveys; HD = high definition; MB = megabyte; GB = gigabyte; Gbps = gigabits per second; FDDI = fiber-distributed data interface; VSAT = very small aperture terminal.

[a]Voice, instant messaging, Wi-Fi, and cell phone.

[b]For example, measurements while drilling, logging while drilling, directional.

[c]Field automation, SCADA, equipment health monitoring.

[d]Video from rig floor and HD cameras on critical equipment, closed-circuit television, monitoring of remotely operated vehicles.

SOURCE: Generated by the committee.

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Study Committee Biographical Information

Richard A. Sears, *Chair*, is a consulting professor in the Department of Energy Resources Engineering, Stanford University, where he develops and teaches courses in energy systems, economics, and oil and gas exploration technology. He was appointed as a member of the Ocean Energy Safety Advisory Committee for the United States Department of the Interior in 2011. He previously served as a member of the National Academy of Engineering Committee on Options for Implementing the Requirement of Best Available and Safest Technologies for Offshore Oil and Gas Operations. He also served as chief science and technology adviser to the National Commission on the BP *Deepwater Horizon* Oil Spill and Offshore Drilling that was established by President Obama in May 2010.

Mr. Sears had a 33-year career with Shell Oil Company and Royal Dutch Shell, where he acquired significant domestic and international experience in the upstream oil and gas industry. His technical and managerial positions included exploration geophysicist, technical instructor, economist, strategic planner, and general management. His managerial positions ranged from exploration and research to fully integrated exploration and production business management, and his responsibilities have included business planning and forecasting, financial responsibility, and staff planning and development. Between 1999 and 2005, Mr. Sears was a vice president for Royal Dutch Shell, where he was responsible for global deepwater technical services.

Between 2006 and 2009, Mr. Sears worked as external research coordinator for the Shell Group and was appointed a visiting scientist at the Massachusetts Institute of Technology (MIT). In this position, he was responsible for managing Shell's energy research activities at MIT and other key U.S. universities and for integrating external research

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objectives with internal technology strategies. While at MIT, he was an active participant in the campuswide Energy Initiative, carried out applied research in energy systems, taught and contributed to courses in several departments, and served as a liaison between the MIT Energy Initiative and oil companies. Mr. Sears is the author of numerous external and internal publications. He received a BS in physics from Stanford University and an MS in geophysics from Stanford University.

James S. Crompton retired from Chevron in 2013 after more than 36 years of working in information technology. Currently, he is managing director of Reflections Data Consulting, LLC. Working as an independent consultant, he is a subject matter expert and senior architect for Noah Consulting, LLC, where he focuses on data management of exploration and production functions and digital oil field programs. At Chevron, in collaboration with the Center for Interactive Smart Oilfield Technologies at the University of Southern California, he worked for more than 10 years to modernize oil fields by using digital technologies. Mr. Crompton is a frequent speaker at Society of Petroleum Engineers (SPE) conferences on topics such as digital–intelligent energy and the data foundation. He was a distinguished lecturer for SPE in 2010–2011 and spoke on the topic of digital technology. In 2013, he coauthored the book *The Future Belongs to the Digital Engineer*. In 1999, Mr. Crompton held the position of chair of the general committee of the Petroleum Industry Data Exchange, the American Petroleum Institute (API) electronic commerce subcommittee. He has a BS in geophysical engineering and an MS in geophysics from the Colorado School of Mines. He earned an MBA at Our Lady of the Lake University.

James S. Dyer holds the Fondren Centennial Chair in Business in the College of Business Administration at the University of Texas at Austin. In 1999, he received the College of Business Administration Foundation Advisory Council Award for Outstanding Research Contributions. He served as chair of the Department of Information, Risk, and Operations Management for 9 years (1988–1997). He was the Philip J. Rust Visiting Professor of Business at the Darden Business School at the University of Virginia in 1999. He is the former president of the Decision Analysis Society of the Operations Research Society of America [now the Institute

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for Operations Research and the Management Sciences (INFORMS)]. He received the Frank P. Ramsey Award for outstanding career achievements from the Decision Analysis Society of INFORMS in 2002. He was named a fellow of INFORMS in 2006 and received the Multiple Criteria Decision Making Society's Edgeworth–Pareto Award in 2006. Dr. Dyer has consulted with a number of companies and government agencies, including the Jet Propulsion Laboratories, the RAND Corporation, and the Department of Energy, concerning the application of decision and risk analysis tools to a variety of practical problems. He has published three books and more than 60 articles on risk analysis and investment science. His recent articles focus on decision making, including a multiattribute utility analysis for the disposition of weapon-grade plutonium in the United States and Russia. He received a BA with honors, Phi Beta Kappa, in physics, with minors in mathematics and philosophy, and a PhD in business quantitative methods and management from the University of Texas at Austin.

Paul S. Fischbeck is a professor in the Department of Engineering and Public Policy and the Department of Social and Decision Sciences at Carnegie Mellon University. He is also director of Carnegie Mellon's Center for the Study and Improvement of Regulation, where he coordinates a diverse research group exploring all aspects of regulation, from historical case studies to transmission-line siting to emissions-trading programs. Widely published, Dr. Fischbeck has served on a number of national research committees and review panels, including the Committee on School Transportation Safety of the National Research Council's (NRC's) Transportation Research Board (TRB); the National Science Foundation's Decision, Risk, and Management Sciences Proposal Review Committee and Small Business Innovative Research Proposal Review Committee; the NRC–TRB Committee on Evaluating Double Hull Tanker Design Alternatives; and the NRC–TRB Committee on Risk Assessment and Management of Marine Systems. His research involves normative and descriptive risk analysis, including development of a risk index to prioritize inspections of offshore oil production platforms; an engineering and economic policy analysis of air pollution from international shipping; a large-scale probabilistic risk assessment of the space shuttle's tile

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protection system; and a series of expert elicitations involving a variety of topics including environmental policy selection, travel risks, and food safety. He is cofounder of the Brownfield Center at Carnegie Mellon, an interdisciplinary research group investigating ways to improve industrial site reuse. He is involved with a number of professional research organizations, including the American Society for Engineering Education, the Institute for Operations Research and the Management Sciences (INFORMS), the Military Operations Research Society, and the Society for Risk Analysis. He has chaired a National Science Foundation panel on urban interactions and serves on the Environmental Protection Agency Science Advisory Board. He holds a BS in architecture from the University of Virginia, an MS in operations research and management science from the Naval Postgraduate School, and a PhD in industrial engineering–engineering management from Stanford University.

James H. Garrett, Jr., is dean of the College of Engineering at Carnegie Mellon University. He holds the Thomas Lord Professorship of Civil and Environmental Engineering. Before becoming dean, he was head of Carnegie Mellon's Department of Civil and Environmental Engineering from June 2006 to December 2012. He is a founding codirector of the Smart Infrastructure Institute (formerly the Pennsylvania Smarter Infrastructure Incubator), a research center aimed at creating and evaluating sensing, data analytics, and intelligent decision support for improving the construction, management, and operation of infrastructure systems. Dr. Garrett also served as co-chief editor of the *Journal of Computing in Civil Engineering* of the American Society of Civil Engineers from 2008 to 2013. His research and teaching interests are oriented toward applications of sensors and sensor systems to civil infrastructure condition assessment; application of data mining and machine learning techniques for infrastructure management problems in civil and environmental engineering; mobile hardware and software systems for field applications; representations and processing strategies to support the usage of engineering codes, standards, and specifications; and knowledge-based decision support systems. Dr. Garrett has published his research in more than 60 refereed journals. He has published more than 80 refereed conference papers, more than 90 other conference papers, and 10 sections or chapters in books or monographs.

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N. Wayne Hale, Jr., is director of energy services for Special Aerospace Services, LLP, of Boulder, Colorado. Mr. Hale provides services in technical consulting and technical analysis, expertise in remote monitoring and control organizations, technical seminars, and advice on organizational culture change. His clientele includes both upstream and midstream oil and gas, wind energy, aerospace, and other organizations concerned with safety, management, culture change, and operations in high-risk environments. Mr. Hale was instrumental in the establishment of BP's Houston Monitoring Center for offshore drilling in 2011. He retired from the National Aeronautics and Space Administration (NASA) after a 32-year career with NASA's Johnson Space Center Mission Control Center. He has a bachelor of science degree in mechanical engineering from Rice University and a master of science degree in mechanical engineering from Purdue University.

Stig O. Johnsen is a senior research scientist in the Department of Technology and Society at Stiftelsen for Industriell og Teknisk Forskning (SINTEF) and a researcher at the Faculty of Information Technology, Mathematics and Electrical Engineering at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. His main research interests include offshore oil and gas safety and security, human factors in complex operations, technology management, resilience engineering, and risk and safety analysis. In collaboration with Norwegian industry and authorities, he established and has chaired the expert forum Human Factors in Control to work to improve safety and resilience through a focus on human factors in design and operations. The forum has existed since 2005. Dr. Johnsen received a BA from the University of Trondheim, an MS in computer science from the Norwegian Institute of Technology, a joint MS in technology management from MIT and NTNU, and a PhD in computer and information science from NTNU related to resilience in complex sociotechnical systems to improve safety and continuity in integrated operations. He has worked as a chief information officer (CIO) in the defense and automotive industries, as a CIO in research and education at NTNU, and as a CIO in banking.

Morrison R. (Moe) Plaisance recently retired as vice president, governmental and industry affairs, at Diamond Offshore Drilling, Inc., after

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more than 45 years of drilling experience, from hands-on supervisory experience drilling and pushing tools to senior management positions working with operators on planning and execution of drilling and completion programs. He has more than 37 years of experience in floating drilling operations with semisubmersibles and drillships in both moored and dynamic positioning modes. He has been involved in drilling and subsea completion activities in water depths of more than 7,000 feet, including work in the waters of the Gulf of Mexico, the North Sea, Australia, the Canadian East Coast, the U.S. East and West Coasts, the Canadian Arctic, Norway, New Zealand, Atlantic and Mediterranean Spain, Brazil, Egypt, Chile, Gabon, Tunisia, West Africa, and Somalia. He participated in the management of the deepest water depth Turnkey well drilled to date, 7,208 feet. He received a BS in industrial management and an AS in petroleum engineering technology from Nicholls State University.

Manuel Terranova is chief executive officer and president of Peaxy, Inc., a highly distributed software-based file and data management solution designed for midtier and enterprise-class customers as well as external cloud. Previously, he served as senior vice president of regional operations and global sales for the Drilling and Production Unit of GE Oil and Gas. From December 2007 through February 2010, he served as head of Subsea Production Systems and Commercial Operations at GE Drilling and Production Systems. In that role, Mr. Terranova managed GE's subsea production equipment portfolio, including subsea trees and controls. From April 2006 through December 2007, he served as general manager of GE's PII Integrity Services. In that role, he served as the business leader for integrity engineering, integrity management, ThreatScan, and GIS software. From April 2002 through April 2006, Mr. Terranova served as the general manager and chief information officer for information management at GE Oil and Gas. From May 2005 onwards, he worked extensively on companywide due diligence and acquisition integration activities. From 1999 through March 2002, he served as manager of e-business strategy for GE's Corporate Initiatives Group. During 2001 and 2002, he led GE's Support Central effort, a knowledge portal that he cofounded with two other GE employees. Before joining General Electric, Mr. Terranova served as Internet program manager of the Xerox Internet Channel and Marketing Group. Based in the Xerox Palo Alto Research Center, he was responsible for designing and

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implementing e-business solutions for Xerox.com. He graduated from Cornell University with degrees in German literature and political science. At the Johns Hopkins School of International Studies, he obtained a master's degree in international economics and international law.

Peter K. Velez is an independent consultant in the offshore oil and gas industry. Before his retirement in late 2012, he was global emergency response manager for Shell International Exploration and Production. His employment at Shell began in 1975. His assignments included drilling engineer; civil engineer; division civil engineer; operations superintendent; production superintendent; manager, production engineering—Gulf of Mexico; manager, health, safety, and environment—Gulf of Mexico; manager, regulatory affairs; manager, regulatory affairs and incident command for Shell U.S. and Americas; and global security manager. As the incident commander for Shell, he responded to major incidents in the Gulf of Mexico and onshore involving oil spills, hurricanes, fires and explosions, and other events. He has received several external awards, including the U.S. Coast Guard Meritorious Public Service Award and Medal (the highest award to a civilian), the API Distinguished and Meritorious Service Awards, and the Offshore Operators Recognition Award. Mr. Velez was appointed by the Secretary of Transportation to the U.S. Coast Guard National Offshore Safety Advisory Committee, on which he served for 7 years, the last 4 years as chairperson. He was a member of the board of directors of the Marine Preservation Association, the largest oil spill response organization in the United States. He was active in various trade association groups. Among other positions, he served as chair of the API Executive Committee on Drilling and Producing Operations; chair of the API Executive Committee on Environmental Conservation; and chair of the Louisiana Health, Safety, and Environment Committee. He was a member of the API Standards Group and the API Safety Committee, and he chaired the API committee that developed, with the Minerals Management Service, Recommended Practice 75, Safety and Environmental Management Program for Offshore Operations. He received a BS and an MS in civil engineering from Rensselaer Polytechnic Institute in Troy, New York.

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Application of Remote Real-Time Monitoring to Offshore Oil and Gas Operations

TRB *Special Report 322: Application of Remote Real-Time Monitoring to Offshore Oil and Gas Operations* provides advice to the Bureau of Safety and Environmental Enforcement (BSEE) of the U.S. Department of the Interior on the use of remote real-time monitoring (RRTM) to improve the safety and reduce the environmental risks of offshore oil and gas operations. The report also evaluates the role that RRTM could play in condition-based maintenance and how BSEE could leverage RRTM into its safety enforcement program.

The report makes recommendations to BSEE about how RRTM could be incorporated into BSEE's regulatory scheme. The recommendations also suggest that BSEE monitor the development of RRTM technologies in relation to risk-based goals governing offshore oil and gas processes.

Also of Interest

Strengthening the Safety Culture of the Offshore Oil and Gas Industry
TRB Special Report 321, ISBN 978-0-309-36986-2, 6 × 9, paperback, forthcoming in 2016

Application of Real-Time Monitoring of Offshore Oil and Gas Operations: Workshop Report
TRB Conference Proceedings on the Web 17, 70 pages, 8½ × 11, electronic, 2015, http://www.trb.org/main/blurbs/173606.aspx

Best Available and Safest Technologies for Offshore Oil and Gas Operations: Options for Implementation
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