Final Report 2015
A summary of 8 years of research-based innovation
As a follow-up of NTNU’s BRU Project in 2004-2005, where 49 companies and institutions in Norway were visited for a survey of key research areas to be focused by universities and research institutes, Integrated Operations was identified as a key research area for the petroleum industry.

Integrated Operations (IO) may be defined as the integration of people, organizations, work processes and information technology to make smarter decisions.

The IO Center was granted status as a Center for Research-based Innovation (CRI) by the Research Council of Norway (RCN) in 2006 and formally started in 2007 as a research center with NTNU as host and SINTEF and IFE as research partners. In addition to the funding from RCN and the research partners, 14 industrial companies have supported the research with funds, expertise and data. Extensive international research collaboration has been a key to the success of the center. Ph.D. candidates and M.Sc. students in addition to researchers at universities and research institutes have been the core of the research activities.

This final report presents highlights of the IO Center and summarizes the research activities in the center for the period 2007-2015 and presents key results obtained. Details of the research projects may be found in annual reports (2007-2013) and in the publications listed in the appendix. All information related to the IO Center may also be found on the web-page www.iocenter.no.

Jon Kleppe
Center Director
Foreword by leader of host institution

The IO Center was one of the first Centres of Research-based Innovation at the Norwegian University of Science and Technology (NTNU), where NTNU has been the host with SINTEF and the Institute for Energy Technology as academic partners. The IO Center has been instrumental in establishing a close collaboration between industry and academia on integrated operations in the petroleum industry. Upon establishment integrated operations was identified as one of four areas in the strategic plan for focused petroleum research at NTNU and is aligned with the NTNU strategies on energy and oceans.

One of the goals of NTNU is to contribute to national value creation on the Norwegian Continental Shelf and to the internationalization of the Norwegian petroleum industry. The IO Center has contributed to this goal by delivering educational competence as well as long-term technical and scientific R&D solutions in close connection with the industry. IO is relevant for several industries and sectors, and during the eight year CRI-period the IO Center has established connections and exchanged experience and knowledge with maritime, defense, aviation and health.

A strong international network of leading research institutions and universities and petroleum companies has provided results enabling more efficient production, and safer and more environmentally friendly operations. A significant number of master candidates have graduated with thesis’ on IO, almost 30 PhDs have been funded through the IO Center, several spinoffs have been established and many associated projects have been and are realized as result of the IO Center at the academic and industrial partners.

For NTNU the IO Center has been a very successful CRI with exiting results within research and innovation and with a significant amount of students working on the topic. In addition, a unique collaboration and network has been established between the academic and industrial partners that will be fruitful for many years to come.

Ingvald Strømmen
Dean, Faculty of Engineering Science and Technology
Norwegian University of Science and Technology
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Vision and goals for the IO Center

Vision

• Be leading international research center for Integrated Operations (IO) in the petroleum industry combining science and practice to develop the next generation solutions for IO
• Giving partners a competitive edge in knowledge and operational performance by bringing new technology to the petroleum industry

Goals

Conduct long-term industrial research of a high international caliber
• 2-4 international break through areas
• Generate at least 2 new solutions/methodologies per year
• Graduate 25 PhD candidates
• Publish at least 5 articles in refereed journals and 10 conference papers per year
• Increase R&D projects initiated by industrial partners

Innovation
• Implement project results in industrial partners’ business processes

• At least one pilot project with each industrial partner
• Establish spin-off companies based on research results
• Educate 25 Master students per year
• Develop and provide continued education courses

Knowledge transfer, networking and collaboration
• 10 user seminars/workshops/courses per year
• Annual international conference on IO
• 2 researchers working on industrial sites every year
• Co-authoring og papers and exchange of researchers

Definition of Integrated Operations

Integrated Operations (IO) is the integration of people, organizations, work processes and information technology to make smarter decisions.

IO is enabled by global access to real-time information, collaborative technology and integration of multiple expertises across disciplines, organizations and geographical locations.
Summary

The Center for Integrated Operations in the Petroleum Industry (IO Center) has been a Center for Research-based Innovation (CRI) in the period 2007-2015. Research partners are NTNU (host), SINTEF and IFE, 8 major oil and gas companies and 5 service companies are the industry partners, while seven international leading universities are academic collaborators. The Research Council of Norway together with the partners in the center have totally contributed with 340 million NOK in funding over the 8 year period that has led to the development of a world-leading research environment on integrated operations.

Research areas the IO Center has focused on are: IO teamwork and capability development, Integrated planning and logistics, Proactive management of safety and environment, Production optimization and subsurface IO, System integrity and dynamic risk assessment, and Telemedicine.

In this period the IO Center has developed a large number of methodologies, software and solutions. Some of these achievements are:

- novel and step-changing capabilities within daily production optimization (CENSO, SmartOpt)
- novel methodology in well testing (SmartX)
- novel capabilities in reservoir optimization (REMSO)
- new methodologies for optimization of well placement
- a real-time risk barometer for online monitoring of the risk picture
- novel visualization tools for collaboration sessions (e.g. planning of logistics, maintenance) (IO MAP)
- a method for on-the-job IO training (SOFIO)
- a structured method for analyzing and allocating tasks between physical locations, organizational units or between human and machine agents (IO MTO)
- a toolbox and framework for integrated planning and logistics (IPL Framework)
- a modular framework for condition monitoring and diagnostics (Mimir)
- a virtual examination room on-the-go for telemedicine

During these 8 years the IO Center has:

- hosted 20 pilot projects in the industry partner companies
- established three spin-off companies: eDrilling Solutions AS, Solution Seeker AS and VISAVI Technology AS
- published 3 books, 75 articles in peer reviewed journals and held close to 250 oral presentations at international conferences
- funded 25 PhD candidates (10 graduating in the end of 2015 and 2016), hosted 12 postdoctoral fellows, 3 visiting professors and educated more than 100 MSc students
- organized the international conference for integrated operations in the petroleum industry 8 times, with a total attendance of close to 2000 participants
Sammendrag


Forskningsområdene i IO-senteret har vært: IO samhandling og kapabilitetsutvikling, Integrert planlegging og logistikk, Proaktiv håndtering av sikkerhet og miljø, Produksjons-optimalisering og IO i undergrunnen, Systemintegritet og dynamisk risikomåling, og Telemedisin.

I denne perioden har IO-senteret utviklet et stort antall metodologier, software og løsninger. Et utvalg av bruddene til IO-senteret er:

- nye og revolusjonerende kapabiliteter innen daglig produksjonsoptimalisering (CENSO, SmartOpt)
- ny metode for brøntesting (SmartX)
- nye kapabiliteter innen reservoaroptimalisering (REMSO)
- nye metoder for optimalisering av brønplassering
- sanntidsverktøy for online overvåking av risikobilde (Risk barometer)
- nye visualiseringsverktøy for samhandlingsøkter (e.g. logistikkplanlegging, vedlikeholdsdeltakere) (IO MAP)
- ny metode for IO trening i jobsituasjon (SOFI0)
- ny metode for struktureret analyse og allokering av oppgaver mellom fysiske lokasjoner, organisatoriske enheter og/eller mellom menneske og maskin (IO MTO)
- en verktøyboks og et rammeverk for integrert planlegging og logistikk (IPL Framework)
- et modulært rammeverk for tilstandsovervåking og diagnostikk (Mimir)
- et virtuelt operasjonsrom for telemedisin

I løpet av disse 8 årene har IO-senteret:

- vært vertskap for 20 piloter hos industriselskapene
- etablert tre selskaper: eDrilling Solutions AS, Solution Seeker AS og VISAVI Technology AS
- publisert 3 bøker, 75 artikler i fagfellevurderte tidsskrift og holdt tett opptil 250 foredrag på internasjonale konferanser
- finansiert 25 PhD kandidater (10 fullfører sin grad i 2015 og 2016), vært vertskap for 12 postdoktorer, 3 besøkende professorer og utdannet mer enn 100 MSc studenter
- organisert den årlige internasjonale konferansen for integrerte operasjoner i petroleumsindustrien med totalt bortimot 2000 deltagere
Organization

The IO Center has been organized with a Center Board consisting of one member from each partner, in addition to a Chair chosen from the center partners. The daily management of the center has consisted of a Center Management team with a Center Director, Operational Manager, a Project Coordinator, and an Innovation & Industry Liaison together with the research program leaders. There has also been a Technical committee consisting of members from the industrial partners and international academic collaborators advising the Center Board and Center Management.

Board

The Board in the IO Center has included all partners and has during the 8 year period conducted 23 Board meetings. The following persons have been Board representatives:

<table>
<thead>
<tr>
<th>Aker Solutions</th>
<th>BP</th>
<th>ConocoPhillips</th>
<th>DNV GL</th>
<th>Eni Norge</th>
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<tr>
<td>Anders Holme (2010)</td>
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<td>Øystein Haukvik (2009)</td>
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<td>Jann Slettbakk (2008)</td>
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<td>Artem Lytkin</td>
<td>Kjartan Pedersen (2011-2014)</td>
<td>Jon Kvalem / Grete Rindahl</td>
<td>16 members, one for each partner</td>
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<td>ConocoPhillips</td>
<td>Brage Sandstad (2008-2012)</td>
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<td>- Deputy chair</td>
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<td>DNV GL</td>
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<td>Eni Norge</td>
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Technical committee

Approx. 60 members from industrial and research partners

Center Management

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<tr>
<th>Center Director</th>
<th>Operational Manager</th>
<th>Project Coordinator</th>
<th>Innovation &amp; Industry liaison</th>
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<tr>
<td>Jon Kleppe</td>
<td>Jon Lippe</td>
<td>Patrick Reurink</td>
<td>Arild N. Nystad</td>
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<tr>
<td>Program manager IO1</td>
<td>Program manager IO2/T3</td>
<td>Program manager IO3</td>
<td>Program manager IO4</td>
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<tr>
<td>Jon Kvalem / Grete Rindahl</td>
<td>Anders Valiand</td>
<td>Lars Bodsberg</td>
<td>Bjarne Foss</td>
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<td>Technical committee</td>
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</table>

Approx. 60 members from industrial and research partners

Program manager IO1

Jon Kvalem / Grete Rindahl

Program manager IO2/T3

Anders Valiand

Program manager IO3

Lars Bodsberg

Program manager IO4

Bjarne Foss

Board

The Board in the IO Center has included all partners and has during the 8 year period conducted 23 Board meetings. The following persons have been Board representatives:
Technical committee

The technical committee has consisted of up to four representatives per industry partner, academic partners and international academic collaborators, and have met 13 times throughout the CRI period. The technical committee has been very important for the scientific quality and industrial relevance of the conducted research, and has been an important meeting arena between industry and academia.

Center Management

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<th>Center Director</th>
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<th>Project Coordinator</th>
<th>Innovation and Industry Liaison</th>
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<td></td>
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<td>Solveig Johnsen, NTNU (2008-2013)</td>
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## Research Program Managers

In Phase I (2008-2011)

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<th>Program 1</th>
<th>Program 2</th>
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<tr>
<td>Drilling and Well Construction</td>
<td>Reservoir Management and Production Optimization</td>
<td>Operation and Maintenance</td>
<td>Work Processes, Team Work and Collaborative Technologies</td>
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<td><strong>Sub-program managers</strong></td>
<td><strong>Program 3</strong></td>
<td><strong>Program 4</strong></td>
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<tr>
<td>Roald Kluge, SINTEF</td>
<td>Stein Krogstad, SINTEF</td>
<td>Davide Roverso, IFE</td>
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<td>Thor Ole Gulsrud, SINTEF</td>
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<td>Torgeir Brurok, MARINTEK</td>
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<td>Torbjørn Korsvold, SINTEF</td>
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<td>Harald Sleire, MARINTEK</td>
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<td>George Halsey, SINTEF</td>
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<td>Aud Marit Wahl, MARINTEK</td>
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<td>Roar Nybø, SINTEF</td>
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<td>Mario Hoffman, IFE</td>
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<td>Svein Hovland, SINTEF</td>
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<td>Espen Kristoffersen, SINTEF</td>
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<td>Grete Rindahl, IFE</td>
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<td>Sjur Larsen, NTNU Social Research</td>
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<td>Eirik Albrechtsen, SINTEF</td>
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<td><strong>Valuation of IO</strong></td>
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<tr>
<td>Asgeir Tomasgard, NTNU</td>
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In Phase II (2012-2015)

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<th>IO1</th>
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<th>IO4</th>
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<td>IO teamwork and capability development</td>
<td>Integrated planning and logistics</td>
<td>Proactive management of safety and environment</td>
<td>Production optimization and subsurface IO</td>
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</table>

**Project managers**

| Grete Rindahl, IFE | Lone Sletbakk Ramstad, MARINTEK | Knut Steinar Bjørkevoll, SINTEF | Vidar Gunnerud, NTNU |
| Arild N. Nystad, PetroManagement | Eirik Albrechtsen, SINTEF | Stein Krogstad, SINTEF |

**T3 – System Integrity and Dynamic Risk Assessment**

| Anders Valland, MARINTEK |
| Telemedicine |
| Arild N. Nystad, PetroManagement |

**Project managers**

| Torgeir Brurok, MARINTEK |
| Per Kristian Norddal, MARINTEK | Jan Gunnar Skogås, St. Olavs University Hospital |
| Ketil Thorvik, St. Olavs University Hospital |
Cooperation in the center and outside the center

IO is about multi-disciplinary collaboration and the IO Center has throughout the CRI period connected researchers from a wide range of backgrounds to conduct research in collaboration with the industry. Seven departments from four faculties at NTNU, four divisions at SINTEF (including MARINTEK) and IFE have been the research partners, and together with the 13 industry partners this has been the consortium in the IO Center.

An effective organization has been made possible by a center management team that has met monthly, a technical committee that has met twice a year with both parallel and plenary sessions, the Board that has met twice a year. In addition, the annual IO conference has been held. The IO Center has had a broad focus while at the same time selecting topical areas to ensure industry relevant deliveries. This has led to that the research institutions have focused on their topical areas of expertise, often more than being truly multi-disciplinary in all projects. Technical committee meetings that have been cross topical have been important to ensure multi-disciplinary work where needed.

A key model of cooperation in the center has been the triangle model; where academia, petroleum companies and service companies have collaborated together on the different challenges. 20 industry pilots have been conducted, making important contributions to basic and applied research that has led to new methods, processes and products in use in the industry.

More than 10 workshops have also been held per year between academia and industry, strengthening the collaboration and facilitating knowledge dissemination. Meetings and workshops have been held both physically and virtually.

International cooperation

The IO Center has had a number of world-leading international academic collaborating institutions as shown in Figure 3.
In addition to these, research departments and international offices of the industry members of the center have been collaborating closely with the IO Center. Examples are CENPES of Petrobras, IBM T.J. Watson Research Center, and the headquarters of BP in Sunbury, UK, and Shell in Rijswijk, NL. In regards to the research areas in the IO Center, the closest collaboration has been with:

- IO Teamwork and Capability Development: Boston University and the University of Central Florida
- Integrated Planning and Logistics: Berkeley
- Proactive Management of Safety and Environment: MINES ParisTech
- Production Optimization and Subsurface IO: Carnegie Mellon University, Stanford University, Federal University of Santa Catarina, TU Delft

Each year there has been 2-4 workshops with the international collaborating research institutions, both in Norway and at their locations. In addition there have been a lot of joint publications and reciprocal researcher visits and student exchanges. The IO Center is a platform that has contributed to establish long term collaboration with many of these institutions.

**Mobility**

Many of the recruited PhDs in the center have been hired for four years, where the fourth year (wholly or partially) has been with residency at one or several of the industry partners. This has both given the PhDs more industrial experience and incorporated the industry partners closer to the center activities. In all, there have been 21 residencies in the industry from the PhDs and postdocs. There has been student exchange between NTNU and the international collaborating research institutions, and PhDs and postdocs in the center have also had shorter and longer visits at the collaborating research institutions.

NTNU has had three visiting professors as part of the IO Center, Erik Ydstie from Carnegie Mellon University, Andrew Hale from TU Delft and Erik Hollnagel from MINES ParisTech, and Bjarne Foss has had a sabbatical leave at the Federal University of Santa Catarina.

**Collaboration**

Collaboration within the IO Center and with the international collaborating research institutions have led to a large number of associated projects and new initiatives both within research and industry. Two examples are:

- Integrated Operations in the High North, a joint industry project with 25 partners
- CRI DrillWell: Drilling and well centre for improved recovery, established in 2010
Communication

Communication and dissemination of research results has high focus in the IO Center. For the partners of the center there have been a large number of events: meetings, workshops and conferences in addition to continuous contacts by e-mail, phone and video meetings to facilitate internal knowledge sharing and dissemination.

During the 8 year period almost 250 conference presentations have been held, and 75 articles in peer reviewed journals have been published. More articles and conference presentations are to come, as several of the PhDs are concluding their work in late 2015 and 2016. The IO Center has also participated in several events hosted by the Norwegian Petroleum Safety Authority, disseminating results.

The two most important arenas for external communication have been the annual international IO conference held by the IO Center, and the IO Center website, in addition to sending out an e-mailbased newsletter 3-5 times a year. The IO Center has also received attention in popular scientific magazines and newspapers as Teknisk Ukeblad and GEMINI.

![Conference papers and presentations by IO Center researchers](image1)

![Journal articles published by IO Center researchers](image2)

To better the dissemination activities and research results the IO Center has developed a user-oriented web site, making it easy to search for and find results.

The web site consists of an open and a restricted area, where the IO Center partners have access to all content. Restricted content will be opened from 1.1.2018, and the website will continue to be updated.

The website has been frequently visited and has since the launch in 2013 had more than 19 000 unique users and more than 2200 downloads.

Whether you are looking for publications or reports based on a single key word, a phrase, a topic or within a specific IO Center project, you can easily find it on the web site.

In addition, iocenter.no will give you the latest information on what is happening in the IO Center, who are the partners, who are contact persons and an event calendar, among other things.

Visit [www.iocenter.no](http://www.iocenter.no) today!
Throughout the whole CRI period the IO Center have hosted the annual international conference on integrated operations in the petroleum industry. This has become an internationally recognized conference where science and practice meet.

This conference has attracted between 250 and 300 participants each year, and has been an important meeting place and arena to present and discuss the latest in IO both from academia and industry. Master and PhD students have also been important attendees at these conferences, connecting science and practice.

A large number of high profile key-note speakers have attended the conference, such as:
- Tord Lien, Norwegian Minister of Petroleum and Energy
- Pål Kibsgaard, CEO and President of Schlumberger
- Helge Lund, previous CEO of Statoil
- Solange da Silva Guedes and Cristina Pinho, Executive Managers in PETROBRAS
- Torstein Sanness, previous Managing Director of Lundin Norway
- Steve Roberts, previous Vice President in BP

The IO Conference has also included speakers from other industries and sectors such as aerospace, maritime, health and defense to get inspiration from leading practice and researchers relevant for the petroleum industry and vice versa.

Much material and most of the presentations held at the conferences are available in both video and PDF-format at www.ioconf.no.
Effects of the center

The IO Center has created a valuable network arena across the academic and industry partners enabling new relations leading to associated projects between R&D and industry and business opportunities between industry partners, in addition to exchange of industry practice and new research results. The IO Center has contributed to much new knowledge on a number of fields: teamwork, capability development, integrated planning, safety and risk management, production optimization and telemedicine.

Value and effects for the industry partners

In general the industry partners are very satisfied with the activities and research conducted in the IO Center, and especially with the network that has been established and the IO Conference. Some comments from the industry partners in the IO Center:
- The IO Center has highly contributed to bring IO on the agenda in Norway, and strengthened focus on IO in the industry
- The industry sees value in implementing results from the various research programs, especially within production optimization, capability development, proactive safety management and integrated planning
- All network activities have been very valuable, maybe as equally valuable to the scientific results of the center
- The membership and interaction with the IO Center has complemented our own internal IO project and the results have the potential to add value to our company

TORE BØ, Operation & Projects Director, TOTAL E&P Norge AS
“The benefit of the collaboration with the IO Center lies both in the increasing knowledge of as well as networking and knowledge sharing. The various IO projects allows both theoretical advancement as well as practical tests through pilots. The IO Center has achieved a high level of competence within its field of expertise, and has succeeded in bringing key players in the industry together in a joint effort to advance further. In TOTAL E&P Norge we have particularly benefited from the IO Center activities applicable in Green Field projects, where technology and team collaboration define the premises for design and operation.”

ERIK SCHIAGER, Manager Area – Non Operated Ventures, ENGIE E&P Norge AS
“The timing of the IO Center has coincided very well with the development of the Gjøa Field, and it has provided us with valuable information and research achievements. The Gjøa Field has been developed with a IO mindset, and Integrated Planning represents an important aspect in this context. Our participation in the IO Center has provided GDF SUEZ with access to IO expertise and industry experiences from a worldwide arena.”

MORTEN DALSMO, Industry Client Leader & Executive Director, IBM
“The collaboration with the IO Center has been a very valuable for IBM. The IO Center has access to a unique network of industrial partners including major oil companies, world class academic partners and renowned research partners. Our engagement in the IO Center has been instrumental in the development of our upstream solutions focusing on turning information into actionable insights in order to enhance exploration and production.”

JON STÆRKEBYE, Senior Vice President Business Development, Kongsberg Oil & Gas Technology
“Kongsberg OGT has gained a lot from the different programs at the center, and our internal R&D programs have been influenced by the experiences we have gained as an active partner in the different projects at the center. Our commercial offerings have also been influenced by the different activities in this dynamic and active research project, involving highly skilled researchers, master students and industry professionals. This is a leading example for other industry research projects.”

Three spin-off companies have been established in the CRI period: eDrilling Solutions AS, Solution Seeker AS and VISAVI Technology AS. Currently, these are employing approximately 25 employees.
Value and effects for the academic partners

Participation in the IO Center has had many positive effects for the academic partners. Firstly, the relationship between NTNU, SINTEF (including MARINTEK), and IFE has become very strong. This has led to a number of common research initiatives funded both by industry and public sources. The establishment of a larger network of leading academic organizations in Europe and the Americas has also strengthened the center, and the long term collaboration between the institutions.

For NTNU and the universities associated with the center the IO Center has given access to much data for student projects and master student thesis, developing candidates that are multi-disciplinary and ready to meet the industrial challenges after graduating. A continued education program within IO, and four master courses in IO have also been developed, providing both students and professionals with the possibility to get IO competence.

The establishment of the IO Center with the vast amount of funding has led to a significant strengthening of the research areas at the involved institutions, and contributed to excellence. Furthermore, methods and prototypes developed in research for and with the IO Centre industry partners have proven to be of both interest and considerable usefulness to other domains.

The close collaboration with industry has led the research institutions to get vast amounts of data and real practice experience in the field of petroleum, enabling applied and industry relevant research. In addition to new projects with the industry partners of the IO Center, this has also attracted interest from other companies to do research projects within the area of IO together with the academic partners. An important measure for the academic partners, and the research institutions in particular, has been the large number of associated bilateral projects generated through the IO Centre participation.

Results and knowledge from the IO Center is also used as input to policy-making by the Petroleum Safety Authority. SINTEF has been a main contributor to the yearly report from the PSA project: “The trends in risk level in the petroleum activity” (RNNP) which aims to measure and improve health, safety and environmental conditions in the petroleum industry.

Effects for the international collaborating research institutions

**Professor Erik Ydstie, Carnegie Mellon University**

“The CAPD engagement in the IO Center during the past years has been very important in several respects. It has provided funding opportunities for PhD students to research cutting edge modeling, control and optimization technology as it relates to integrated operations in the oil and gas sector. Several students, have been able to benefit from joint work between NTNU and CmU. Conference proceedings and papers have been generated. One important aspect of the activity is that it supports an Adjunct Professorship at NTNU. This position allows for co-supervision of students and the presentation of a very popular course module on adaptive control for final year students at NTNU every fall.”

**Professor Khalid Aziz, Stanford University**

“By collaborating with the IO Center we have been able to enhance and apply our developments to real field situations. This is very valuable for us.”

**Professor Jan Dirk Jansen, TU Delft**

“Both at TU Delft and at NTNU, the combination of systems and control theory and petroleum engineering proved to be very fruitful and rich in opportunities. An important benefit of the cooperation were the regular personal contacts between researchers from both institutions, and from other IO partners or collaborators such as SINTEF, Stanford University and Carnegie Mellon University, e.g. at each other’s sponsors meetings or PhD defenses, or during researcher exchange visits.”
Training of researchers

The combination of PhD and master education, together with researchers has been an unbeatable combination for the IO Center. PhDs and master students have been fully immersed into IO Center research projects. This has provided us with a strong platform with a diverse set of instruments for cooperation with IO Center partners.

A central strategy for the IO Centre as a CRI has been to integrate fundamental research, applied research and industrial innovation. The PhD students have mostly been hired for 4 years, including 25% industrially related project work. They are integrated in project teams and are engaged in field work tasks. The PhD students exchange ideas and results through colloquia groups, and are supervising master students in IO projects. Several of the PhD candidates also participate in exchange programs at the international collaboration partners and produce joint publications.

As of 1 September 2015 a total of 30 PhDs have been associated with the IO Center. Of these 25 are directly funded, while 5 are funded by other sources. 10 of the PhDs are not finished with their PhD as of this date. The remaining 20 are currently employed as follows (3 of the 20 work outside Norway):

Employment of PhD-candidates

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</table>

Story of two PhD candidates

**Vidar Gunnerud, CEO of Solution Seeker AS**

I started working in the IO Center in 2007 on the topic of daily production optimization, as part of my PhD education. After defending my degree in 2011, I stayed on three more years as a post doc researcher. Our research group started generating interesting results with commercial potential already back in 2011. The prospects of a spin-off company was an important reason for me to continue working at NTNU and the IO Center after defending my degree. In November 2011, we filed our first patent, and after a year of preparations and commercial discussions Solution Seeker was established in January 2013.

The spin-off company started out with a NTNU Discovery project. Two students, Professor Bjarne Foss and myself were working evenings for six months, before the first fulltime employ started during the fall of the same year. In 2014 I stepped down to a 50% position at NTNU to be able to contribute more in the company, and in January 2015 when my post doc position ended at NTNU, I joined Solution Seeker fulltime as CEO. Since its start two and a half year ago, the company has grown rapidly. Today the company has seven full time employees, and is working closely with ENGIE and ConocoPhillips on developing its technology.

For me, it has been interesting and I have learned a lot from working at NTNU in close collaboration with the IO Center partners. My research has been driven by real problems since day one. To be able to follow your own research into the commercial arena through a spin-off company, and see it generate real value, is extremely rewarding.

**Mansoureh Jesmani, PhD candidate at NTNU**

The IO Center provides an opportunity to define challenging PhD projects regarding demands of industry. Therefore, applicability of the developed methodologies is one of the main important aspects of research in the IO Center. Moreover, the collaborative working environment of the IO Center promotes knowledge sharing and team working.

Doing a PhD in the IO center gives me the opportunity to face many interesting problems in closed loop reservoir management and I would like to continue my career in this field of study.
Master education

The IO Center has provided master students at all educational institutions in the center with research topics for projects and thesis. In all, 102 thesis have been written to date (see figure 5, and details in Appendix 2). In all, 113 master students have written these thesis’s, 1/3 being female and 2/3 being male.

Some of the master students have been closely connected to the IO Center research activities, and participating both in technical committee meetings and at the IO Conference.

The Norne Benchmark Case dataset made available by industry partner Statoil has provided data to more than 30% of the master students. In addition, an own Experts in Team course has been held at NTNU in collaboration with Statoil focusing on this dataset to develop new ideas for better reservoir characterization and enhanced production.

Some master students have also had summer internships in the industry partner companies.

Most master students have upon graduation been recruited to the industry, while a small number have continued in academia in PhD positions.

Continued education

The IO Center has collaborated with the new experience based Master of Science in Oil and Gas Technology at NTNU to develop a study specialization in IO (30 study points). The IO specialization will start up in autumn 2016, and will consist of the following four courses:

- Introduction and overview of integrated operations
- Team communication and decision making in IO
- Collaborative technologies for IO
- Safety and risk in IO

The chosen specialization will form the basis for the topic of the master thesis. This IO education can provide the partners of the IO Center and from other companies and industries a possibility to increase the IO competence.

The learning outcomes for the IO specialization module are:

- Use existing technical education to see new possibilities that can be realized with integrated operations.
- Be able to link research based knowledge within integrated operations to one’s own organizational experience and use the knowledge both in a critical and constructive way in concrete work situations.
- Be familiar with the knowledge front and the most important challenges within the domain of integrated operations.
- Skills, the candidate shall:
  - Be able to use the knowledge actively, master the IO area’s terminology, participate in IO domain oriented discussions, communicate one’s own domain knowledge and be able to pinpoint important IO elements in planned development processes in one’s own organization.
  - Have skills related to work and lead integrated teams.
  - Have the skills to plan and lead changes processes enabled by IO.

Contact person: Vidar Hepsø (vidar.hepso@ntnu.no).
## Financing

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All figures in kNOK

## Results – key figures

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Research and research plan

Integrated Operations was targeted as the next generation of efficiency development in the oil and gas industry in the mid-2000s. There were work groups on IO in OG21 (Oil and gas in the 21st century - OG21, is the Norwegian national petroleum technology strategy), Norsk olje&gass (then OLF, the Norwegian Oil and Gas Association) and the Norwegian Petroleum Directorate. In the Better Resource Utilization report (BRU), a strategic plan and NTNU and SINTEF 49 companies and governmental agencies were interviewed and pointed out IO as one of four prioritized research areas. The major industrial challenges that needed to be continuously addressed were the integration of different - and very demanding - technologies together with new work processes. These have to be integrated and become functional in real time. A gap analysis pointed out the following areas as especially demanding:

- Well planning and drilling execution in real time.
- Reservoir management and production optimization in real time.
- Operation and Maintenance planning and optimization.
- Integration along the value chain and across time scales.

Based on this, feedback from the industry partners, and ongoing research at NTNU, SINTEF and IFE, the IO Center established four research programs (see figure 1) in Phase I (2007-2012). Program 1 was led by SINTEF, Program 2 by NTNU, Program 3 by MARINTEK, and Program 4 by IFE. The IO Center has worked as a virtual center with activities mainly in Trondheim at NTNU and SINTEF, and in Halden at IFE.

To secure industrial relevance and interest an important part of the research has been case studies and pilot projects in an industrial setting, in addition to a large number of meeting places between industry and academia for discussion and knowledge transfer.

Feedback and recommendations from the Midway evaluation

Conclusions and recommendations to the centre

(RCN Midway evaluation in 2010)

IO Center has rapidly grown into an efficient and research organization with strong support from industry and producing results that create considerable potential for innovation in the petroleum industry and its suppliers. We commend this achievement and note that it would be a considerable loss if the high and coherent competence represented by IO Centre were not preserved.

For further improvement of the Center, we recommend:

- that the research program for the final three years be focused by definition of interaction projects between the sub-programs
- that the planning for preservation of IO Center resources after year 2014 be continued
- that the current proposals for future research in Programs 1 and 4 be reviewed once the findings from the enquiry into the recent major incident in the Gulf of Mexico are available.
- that the affiliation to IO Centre be mentioned by authors of scientific articles and conference presentation
- that a new Chairman of the Board be appointed, preferably delegated from an industrial partner.
Adjusted research plan

The IO Center has operated in accordance with the initial visions and goals throughout the whole period, but some adjustments to the research plan have been done.

Based on the self-evaluation in connection with the Midway evaluation, advice from the Board and technical committee, and the Midway evaluation conducted by the RCN in 2010 the IO Center decided to re-organize its research programs to research areas for Phase II (2012-2015). This was to facilitate more cross-institutional work and more interaction between the research programs in the center. In addition the Macondo blowout and explosion on April 20 in 2010 led to an increased focus on risk management, which was decided to become an own research area.

As a result, the research structure was revised and cross-institutional and cross-research program research areas were established (as shown in Figure 2).

Continuation beyond 2015

The IO Center has worked actively on continuation beyond the CRI period, and many associated research projects and JIPs with industry partners continue beyond 2015. The research partners will sign a Memorandum of Understanding focusing on common activities within research, development and education and have regular meetings on the field of IO. A program for continued education and university education within IO is established at NTNU, starting in 2016. Elements from the IO Center also continue in other research centers, such as SFF AMOS (Centre for Autonomous Marine Operations and Systems), SFI DrillWell (Drilling and Well Centre for Improved Recovery), SFI SUBPRO (Subsea Production and Processing), SFI Marine Operations, and SFI Offshore Mechatronics.
The establishment of the IO Center made it possible to bring together world leading research institutions and industry companies within integrated operations in the petroleum industry. A large number of methods, software and solutions in a broad variety of areas have been developed. In the following pages the highlights from the research areas in the IO Center are highlighted.

**Highlights of scientific results**

**Awards**
- 2009 Best paper at 12th International Conference on Business Information Systems in Poznan, Poland: Darijus Strasunskas
- 2010 IBM Open Collaborative Faculty Award: Bjarne Foss
- 2011 IBM Open Collaborative Faculty Award: Bjarne Foss
- 2012 IBM PhD Scholarship Award: Bjarne A. Grimstad
- 2012 IBM PhD Scholarship Award: Brage Knudsen
- 2014 ABEPRO Award to the Best Master Thesis (from The Brazilian Association for Industrial Engineering and Operations Management) to Claudio Lima
- 2014 Most meritorious publication on the topic of safety and loss prevention in an IChemE publication (from Safety & Loss Prevention Group) to Nicola Paltrinieri

**Key notes**
- 2013: 10th IFAC International Symposium on Dynamics and Control of Process Systems in Mumbai, India: Bjarne Foss
- 2015: 2nd IFAC Workshop on Automatic Control in Offshore Oil and Gas Production in Florianópolis, Brazil: Bjarne Foss
IO Teamwork and Capability Development

How can we build sustainable IO?

IO is a way of working, supported by new technologies, new processes, new governing principles – and people thinking and acting differently. Like any new way of working, IO cannot be purchased ready to go, but has to be developed. After initial changes are introduced, people and organizations do have a tendency to revert to familiar ways of working, and both vigilance and good tools are required to make sure we all stay on the case and really reach our goal. The outcomes of these research activities include tools for development of capabilities, for collaboration assessment, mindsetting and training and for improved interfaces.

The Capability Approach to IO

Together with Statoil, Shell and the Boston University School of Management, the IO Center has worked on capability development in IO.

A main obstacle to development and implementation of Integrated Operations (IO) is the lack of efficient tools for operationalization of an IO philosophy in the early project phases that supports the development and implementation through the whole project process. The IO Center capability approach addresses this challenge by offering a way of ensuring an understanding of requirements for performing operations in accordance with the operational concept by addressing the whole system in the current operational context.

An organizational capability is based on resources involving people, process, technology, and governance that directly creates added value. Getting the most out of IO implementation in an organization requires focus on all these aspects of the capability. The IO Center approach addresses how we configure these resources to enable performance.

Findings include:

- Realizing new levels of IO requires tools that support IO development that is more integrated with the companies’ project models than today.
- For projects to ensure sufficient maturity in their IO capabilities, early project identification of the resources that are necessary to develop, support to developing project plans, and evaluating the maturity of the IO implementation is needed.

IO MTO

IO MTO: Analysing and allocating tasks between physical locations, organisational units or between human and machine agents.

Structured method for analysing and allocating tasks between physical locations, organisational units or between human and machine agents.

The IO MTO method was initialised under the CORD Optimal Operations and Control project in collaboration with Statoil, ConocoPhilips, BP, SINTEF and Marintek, and has been further developed by IFE through case analyses of offshore and onshore installations.

There are five main phases in the IO MTO method, which consist of the following activities:

Define goals; Map roles and tasks; Test hypotheses for reallocation; Model the organisation; Consequence analysis.
Visualization tools and teamwork principles to improve collaboration, planning and safety

IO teams often consist of participants from several other teams or units with different competencies and at different locations who collaborate for a certain purpose. The coordination of an IO team's activity occurs in a regular collaboration session, like a production optimization meeting or a plan meeting, where team participants get together by means of collaboration technology.

SOFIO IO Collaboration Training

Method for training and assessment of IO Collaboration, Structured Observation with Feedback of IO interaction

The first version of the SOFIO method was developed in phase I in a case study with Statoil focused on identifying traits of successful collaboration. The observation method gave significant and measurable training effect.

It was then further developed into a full training method by IFE in bilateral projects, adding IFE solutions from nuclear and defense training to expand the scope of the method. SOFIO provides highly operationalized on-the-job collaboration training, as well as work process training.

SOFIO has been employed by IFE in training the operations organizations at Gjøa (ENGIE, 2009-2013) and Goliat (ENI, 2012-2013)

IO Teamwork

What is an IO team?

An IO team has a combination of different competences, and through discussions and exchange of information they try to develop a correct situation understanding on which to base decisions and actions in order to achieve a common goal.

IO teams may be defined as teams that:

- are directed at achieving an operational goal, e.g. maintaining the uptime of the facility or ensuring optimal production.
- are distributed across geographical locations.
- use collaboration technology to bridge the gap between locations.
- consist of participants from different disciplines or organisational units.
- use a main collaboration meeting to coordinate the work in the team.

In addition, IO teams usually have the following characteristics:

- Each team participant is in the team as a representative of his or her respective organisational unit.
- Team participants may change over time or from situation to situation because of offshore shift schedules or because roles are rotated between different individuals.

The project has established training methods, requirements to collaboration technology and methods for training assessment. Key result of the research on IO Teams are in addition to publications communicated in a handbook and guideline for IO Teamwork and a handbook on Collaborative Environments.
VISAVI Technology AS – Next Generation Planning Tools

VISAVI LivePlan is a new type of planning tool that promotes safer and more cost-efficient operations of offshore petroleum installations. LivePlan displays work order plans, operational plans and plan-related data, such as work permits, helicopter bookings and weather forecast, on a large touch screen. By integrating data typically residing in disciplinary silos onto a shared work surface, LivePlan can play a key role in facilitating interdisciplinary collaboration. This ability is strengthened by the use of a large screen, providing a natural arena for discussions and information exchange among colleagues. Furthermore, since LivePlan is available 24/7, requires no training, and shows “live” data, it is easy for everyone to stay informed, facilitating shared situation awareness.

LivePlan has been funded by and co-developed with ENGIE EPN and its Gjøa organization. It has been in operation at the Gjøa platform, and onshore at the supply base in Florø and in the operation center in Stavanger, since July 2014.

VISAVI Technology is a spin-off company from the Institute for Energy Technology (IFE), building on research conducted at the IO Center, NTNU and IFE. The Norwegian Research Council and Innovation Norway have supported the commercialization process. VISAVI has currently three full-time and three part-time employees. For more information, please visit www.visavi.no or email info@visavi.no.
Integrated Planning and Logistics

Integrated planning – key to pro-active operational management

Integrated Planning (IPL) represents a holistic perspective on planning, emphasizing the interplay between planning horizons, organizational units, and among cross-organizational partners. Based on long-term collaboration with industry actors – PETROBRAS, Statoil, and Aker Solutions – there has been an explicit focus on developing tools and methods supporting IPL within offshore operations. The approach has been to collect and analyze experiences within planning practices from the involved actors, but also on delivering specific recommendations for improved IPL practices. The main focus has been on how to advance human, organizational and technological capabilities through the prospect of more robust planning practices, while also on how experiences from the ‘sharp end’ of operation can be incorporated into planning practice and organizational capabilities.

The IPL Learning Lab

The IPL Learning Lab provides a structured approach for jointly creating, refining and applying robust and adaptive IPL practices. Since both structure and content can be tailored according to company-specific needs and IPL maturity, it can be used of companies in different phases of IPL development. This provides a unique opportunity for an improvement project and learning arena.

Back-to-back with the IO14 Conference a Pilot of the IPL Learning Lab assembled a wide range of participants from industry and academia spanning across company and geographical boarders. The workshop formed a creative environment for mutual exchange of knowledge and experience, with a particular focus on how to advance Integrated Planning (IPL) practices within the petroleum industry.

The main objectives of the IPL Learning Lab were:
- Presenting results and tools from research within the IO Center and how it can be applied by the industry partners for IPL improvements.
- Knowledge sharing between industry partners and presentation of experiences, methods and tools applied for improved IPL, especially at tactical level.
- Testing the concept of the IPL Learning Lab and evaluating how it can be useful for industry partners as an efficient tool for learning and improvement of IPL practices.

The IPL eBook

The IPL eBook is a comprehensive guide into the field of Integrated Planning (IPL). Written to provide a complete description of the core elements for design and facilitation of IPL best practices, it is also possible to use individual chapters (e.g. methods and tools) and to combine these with other handbooks of the IO Center (e.g. The IO Leadership Handbook, The IPL Handbook, The IO Teamwork Handbook). The eBook further provides electronic links to relevant material from other sub-projects such as links to illustrative videos, presentations, and especially emphasizing the handbooks.

Moreover, a main topic of the eBook is the IPL Concept where the common theme is the need for interaction and coordination across different boundaries and plans. Making interaction and coordination efficient by (re)design and facilitation of IPL best practices is therefore a key assumption and goal. In addition to the system approach to IPL best practices, change management aspects of how to implement an IPL best practice are also presented.
The IPL Screening Tool

Within IO2 significant efforts have been put into developing the IPL Screening Tool. The main objective of the tool is to assess the maturity and quality of existing planning practices for the prospect of internal and external benchmarking, identification of areas for improvements and identification of “best in class” – who to learn from. Its function is to obtain a holistic view of the maturity of planning practices based on the IPL Capabilities. The tool consists of a web-based survey and questions organized according to the IPL Capability Model. Relevant respondents are people involved in IPL, and especially key personnel such as planners, managers, owner of plans, task responsible, etc.

For different levels (company level, unit level, field level etc.), results of the data analysis are presented as IPL maturity and Quality of Planning Practices (Figure 1 and Figure 2). In addition results and analysis can be provided for each of the IPL capabilities, the two main groups of capabilities and for different roles (groups of respondents). Especially analysis of enabling capabilities (organizational and technological enablers) versus human and cultural capabilities provides an interesting basis for selection of improvement measures.

The IPL Model

The IPL Capability Model represents the core basis of our R&D efforts and contains three enabling capabilities and four human and cultural capabilities which characterize efficient IPL practices. The IPL enabling capabilities – Roles and Processes, ICT, Arenas for plan coordination - constitute key elements related to IPL which the management can design and implement according to the specific needs of the organization. The human and cultural capabilities – Commitment, Competence, Collaboration and Continuous learning - represent the qualities of a proactive and resilient organization.

The IPL Toolbox

The IPL Toolbox is a collection of methods, publications, handbooks and concepts developed through the course of the IO project, Phase I and Phase II. Individually and collectively they can be applied by researchers for further investigations into the topic of integrated planning, or by the industry themselves as part of internal improvement programs.

- IPL eBook – a comprehensive guide into the field of IPL
- IPL – Screening Tool – a quantitative and qualitative investigation of IPL Maturity
- IPL Root-cause analysis – for prevention of problem reoccurrence
- IPL Roadmapping – for structuring of improvement processes
- The IPL Handbook – the manager’s guide to Integrated Planning
- The IPL Storyboard – success stories from the industry
Improved risk decision support during daily operations and planning

The main research objective has been to develop knowledge, methods and guidance for smart use of IO-related solutions in daily risk management. Key research questions have been:

- How can better access to real-time data lead to improved safety?
- How can IO solutions provide improved support to onshore/offshore decision-making processes?

Models, methods and visualization tools have been developed for online monitoring together with a handbook for robust work practice in integrated operations.

### Risk barometer for online monitoring of risk picture

How do changes in barrier status influence the risk level on the installation?

Several petroleum companies have implemented technical integrity management programs to provide operators, engineers and management with a comprehensive and readily accessible overview of the integrity of technical safety barriers. These overviews, which are generally updated every month or every other month, do not give a direct link to changes in risk level. In fact, a major challenge in present methods for risk control of major accidents is the inability to continuously monitor changes in risk level, thereby limiting their suitability to provide decision support during daily operations and planning. Furthermore, monitoring of risk level should not only consider integrity of technical safety barriers, but also operational and organizational factors. In the IO Center risk-based indicators have been identified which allow for online monitoring of changes in barrier status. A stepwise approach for developing indicators has been applied based on barrier functions and systems to prevent and mitigate major accidents. Barriers and risk indicators have been developed for process events, ship collisions, drilling events and loss of containment (sand erosion). The indicators are developed together with subject matter experts considering both technical, operational and organizational factors using the quantitative risk analysis (QRA) as a starting point, and complemented with barrier analyses. During method development we have included core competence in nuclear industry risk assessment provided by IO Center industry partners. To visualize the risk picture, a risk barometer demonstrator has been developed with drill-down functionality. The demonstrator presents changes in instantaneous risk level as well as trends over the last periods. The risk barometer may support typical decisions such as the maximum number of work permits to be approved in a particular area and when to limit maintenance work in hydrocarbon areas.

Visualization of the risk picture

Pla$orm  Live  Risk  Visualiza3on

Visualiza3on  choices

Pla$orm  Visualiza3on

0
7
14
1-­‐Jan
1-­‐Feb
1-­‐Mar
1-­‐Apr
1-­‐May
1-­‐Jun

Platform Live Risk Visualization

Risk Monitor UI
Handbook on robust work practices in the petroleum industry

Sensemaking is the process by which people give meaning to experience. It is a social process, not merely an individual, cognitive process. Sensemaking can be critical to safety because the first signs of a problem that may develop into an accident are often weak or ambiguous, and may therefore be ignored. Integrated operations change the preconditions for sensemaking by giving access to more real time data, providing new visualizations of such data, connecting operating personnel and technical specialists in real time and by reducing the time to reach a decision. According to IO Center field work in rig-teams in an onshore operations center and in medical operation rooms, more focus should be given to support “work as done”, i.e. actions and practices that go beyond plans and procedures. An important deliverable has been a handbook presenting guidance on robust work practices and collaboration in drilling operations. Unfortunately, there are no ready-made solutions for many of the challenges of practice and safety in IO. Many of the themes addressed in the handbook are associated with dilemmas whose solutions are neither generic nor given, but must be negotiated in the specific domain (e.g. drilling, production, maintenance) and context where they appear. Handbook themes are grouped into three main areas that correspond to different levels in the organization, from the sharper - hands on - to the blunter – organizational - ends.

• Level 1: How to behave and collaborate in multi-disciplinary teams in an IO setting?
• Level 2: How to work with procedures and responsibilities under varying conditions?
• Level 3: How to configure an organization for IO?
Resilience Engineering and Integrated Operations in the Petroleum Industry

The deployment of IO significantly changes established ways of working; this creates new possibilities as well as new risks. The industry must be prepared for both in order to maintain or improve current levels of safety and efficiency. The use of IO requires an approach to safety management that can cope with the new challenges as well as the opportunities. Resilience Engineering has been developed to cope with increasingly complex socio-technical systems that often pose a challenge to established safety approaches. It provides a way to address the issues of emergent accidents and the often disproportionate consequences that may be the result of ever more complex technologies and integrated actors. Resilience Engineering methods are therefore going to be important tools in the management and assurance of safety in current and future IO systems. A white paper has been published which provides an overview of Resilience Engineering and seeks to answer the following questions:

- What is Resilience Engineering?
- Why do we need Resilience Engineering in integrated operations?
- What is the significance of performance variability?
- How does Resilience Engineering work in practice?
- How does Resilience Engineering fit with other safety management approaches?
- How mature is Resilience Engineering?
- What is the added value of Resilience Engineering for integrated operations in petroleum production?
Production Optimization and Subsurface IO

Increasing amounts of real time data are made available to the petroleum industry through improved instrumentation and compatible data systems. Our goal has been to convert real time data into high quality advice for use in operational workflows. This is done through an ensemble of methods like techniques that simplify online model calibration and powerful optimization methods that enable the use of optimization in daily operations. We have introduced new capabilities that for the first time enable real time production optimization in practice. Tests and evaluation have been performed together with several IO Center partners. One concrete example is tests performed on a PETROBRAS FPSO as detailed in a separate text box below.

New capabilities in daily production optimization

The IO Center has developed CENSO, an open source state-of-the-art software for computer assisted production optimization. The software has been successfully tested together with BP on two production systems. Tests indicate a potential to increase production by more than 3% - equivalent to 100 million USD per year at 65 USD/barrel (current oil price). The new technology allows for more efficient operation of existing fields, only at the cost of installing and maintaining software. Similar optimization technologies have previously been tested together with FMC, Statoil, and Petrobras. IBM has contributed to the development by awarding two PhD Scholarships on 20 000 USD and sharing their software solutions for optimization. Optimization technology is important for increasing revenue from existing fields and for operating the fields of the future.

CENSO is available as open source software at github.com/bgrimstad

MRST – open source reservoir simulation for optimization

Numerical simulations are important tools to predict future production from reservoirs. Large resources are put into development of commercial reservoir simulators, but for research purposes, the value of protected black-box simulators is often limited due to lack of access to source code and/or license restrictions. During the last few years Dept. of Applied Mathematics at SINTEF ICT have been developing MRST (Matlab Reservoir Simulation Toolbox) as part of their research, and the code is distributed freely as open source. The usage of MRST is steadily increasing. Its popularity is due to low user threshold and at the same time ability to cope with the complexity of industry standard models.

Through the IO Center the focus on MRST development has been reservoir simulation for optimization. This means emphasis on robustness, efficient gradient computations, and exploiting potential for speed-up through model reduction. The combination of these properties was demonstrated on a case study of the Voador field (Petrobras operated field) where simulation time was reduced from hours to minutes while retaining sufficient accuracy enabling efficient optimization of predicted field NPV. In addition to model reduction, a suite of fast flow-based proxies has been developed for optimization and visualization purposes. The technology was applied to the Norne benchmark case (a field operated by Statoil), and provided an optimal strategy within minutes.

MRST has been used in case studies on models of fields operated by Petrobras, Total and Statoil. In addition, its usage is expanding with our research partners. A considerable amount of course material based on MRST has been developed.
Novel capabilities in reservoir optimization

Reservoir control optimization is a challenging problem for several reasons:
- High number of parameters and states needed to represent the reservoir.
- Non-linearities in the involved equations.
- Additional constraints that must be satisfied by plausible solutions.
- Uncertainty in reservoir parameters.

The IO Center has developed a completely new approach to reservoir optimization. This method goes under the name REMSO (REservoir Multiple Shooting Optimizer) and exploits parallelism, reduction techniques and automatic differentiation. The objective is to promote reservoir simulators as decision support tools covering constraints provided by reservoir and production engineers. REMSO is tightly interfaced with MRST (MATLAB Reservoir Simulation Toolbox). NTNU, UFSC in Brazil and DTU in Denmark together with Petrobras have been collaborating in this project.

A key property of the methodology is the ability to handle control optimization problems with thousands of constraints. REMSO is available as open source software at [github.com/iocenter/remso](https://github.com/iocenter/remso).

This first work inspired many new research directions:
- The development of algorithms with better convergence properties, compared to state-of-the-art optimizers.
- Uncertainty handling. REMSO is being extended to take into account constraints from different scenarios and to quantify risk and uncertainty of solutions.
- The integration of reservoir and oil gathering network simulators to find even more realistic production plans in the short-term perspective
- Exploitation of simulator based constraints by the optimizer. REMSO has inspired an optimization technique including constraints directly in the reservoir simulator rather than in the optimizer, aiming efficiency in typical application settings.

REMSO is still under continuous development and these new capabilities will be made available as soon as their methods are peer-reviewed in journal articles.

Well placement optimization

A key challenge within a field development campaign is to find reasonable locations for where to drill and subsequently perforate wells. Commonly, the field development effort is guided by field studies and engineering experience about the particular reservoir.

Our task within the IO Center has been to apply optimization theory to the well placement problem. Within this effort, we have successfully established an optimization framework that relies on the implementation of both efficient search algorithms, and of constraint-handling techniques capable of dealing with a variety of practical constraint formulations. The methodology has been developed in cooperation with Stanford University and IBM Research.

The well placement methodology has been tested on various cases, including a comprehensive field case. Key industry partners have been Total E&P and Statoil.
Solution Seeker – An IO Center spin-off company

Solution Seeker is developing a new generation of decision support tools for petroleum production optimization. The technology is being developed and tested in close collaboration with selected partners.

Every day petroleum production engineers face a challenging task when they have to decide the settings for their oil-producing asset. Due to numerous dependencies, even small adjustments in choke valves or artificial lift settings can create significant changes in daily production value. Solution Seeker aims to develop into a truthful knowledge and software companion within this domain. Combining the expertise of the operator and production engineer with our unique technology can access an until now untapped production potential.

Solution Seeker is a spin-off company that originates from the IO Center. The technology is based on an 8-year collaborative research project including NTNU, SINTEF and numerous industry partners. Currently Solution Seeker has 6 full time employees. The technologies are based on a solid theoretical foundation as well intimate understanding of the oil industry’s challenges in daily production optimization.

For more information please visit www.solutionseeker.no.

Norne Benchmark Project

The Statoil-operated Norne Field offshore Norway has been in production as a subsea field since 1997, mainly through water injection. The expected ultimate oil recovery is more than 60%; probably the highest recovery of all subsea oil reservoirs, worldwide. In 2010, the Norne license partners agreed to release large amounts of subsurface data from the field for researchers world-wide to test and compare models and algorithms on a common set of real-field data. Thus, the IO Center provides support to users worldwide; the data is for nonprofit research institutions and universities. More than 150 researchers at 25 different institutions have used the Norne dataset.

A Joint ’10 Center-SPE’ workshop on the Norne data from 26.6 to 27.6.2013 was held in Trondheim. The workshop attracted 80 delegates and international speakers from eight countries worldwide; United States of America, Netherlands, Brazil, Denmark, United Kingdom, Canada, China, and Norway. See also www.spe.org/events/13atro/

Further information is available on the IO Center web site.

The Norne Benchmark Project has been valuable in education of master students, making it possible to explore different hypotheses and develop methods based on data from an existing field.

The Norne dataset has also been the basis of the Experts in Teamwork “Norne village” course at NTNU held since 2010. This gives the opportunity to students from different disciplines to collaborate on projects with realistic data.
System Integrity and Dynamic Risk Assessment

Condition and performance monitoring has been embraced by the oil and gas industry in increasing fashion during the past 10 years. The art of monitoring equipment for the purpose of maintenance planning and execution requires skills in measurement technology, data capture and analysis. Work has been done on describing typical topside process equipment (safety critical emergency shutdown valves, production separators and production heat exchangers) where oil and gas operators did not have sufficient solutions available for condition and performance monitoring, and how to dynamically perform risk assessments of such equipment.

### Methods for assessment of condition monitoring system capabilities

#### Safety critical valves
Developed a solution for frequency domain analysis of acoustic leakage signals to determine leakage size with better accuracy.

#### Production separators
Developed a technology based on passive acoustic markers to enhance the ability to perform non-intrusive assessment of the internal condition of the separator, thus creating information that may be used to enhance maintenance decisions and planning.

#### Heat exchangers
Developed a methodology for selecting the appropriate condition monitoring for different types of equipment.

### Mímir - a modular framework for condition monitoring and diagnostics

The Mímir platform has been developed to be a tool for processing raw data and transforming it into meaningful information for maintenance and operational planning. It is based on accepted industry standards and aims at providing a standardized and expandable set of tools that can be easily combined to quickly implement and deploy advanced decision support functions and business solutions.

Mímir aims to be a complete condition monitoring and diagnostics platform that facilitates the study, implementation, and testing of recombination of pre-developed modules into new configurations which would then be optimally designed to solve specific condition monitoring and diagnosis tasks.

### Choke valve failure prediction

The Mímir platform was used to demonstrate an ability to predict failure in a production choke valve, with 14 days lead time using case data from Statoil.
Telemedicine of the Future for O&G

The project vision has been to improve the healthcare services at offshore installations. The objective has been to develop decision support for real-time remote medical decisions between the offshore platforms and the hospital: “Virtual Examination Room (VER) – on the go” in order to make good quality decisions within 2-5 minutes. The project has been developed as a user-driven innovation process and a tri-part collaboration case study between St. Olavs University Hospital, ConocoPhillips and IBM together with the IO Center. Further, the project has had workshops with the industrial partner Petrobras and Albert Einstein Hospital in Sao Paulo.

The Virtual Examination Room – on the go

The main results from the initial project triggered the motivation for exploring the concept of a “Virtual Examination Room – on the go”. The objective is to make good quality decisions within 2-5 minutes. One of the success factors to achieve this is to be able to provide the medical specialist with enough medical information no matter where he is – “on the go.” The “Virtual Examination Room” is a collaboration space; in which all medical data can be accessed and the decision-making process may unfold in real time. A prototype VER was set up by IBM. The virtual examination room can be accessed by PC/tablet/smartphone “on the go”. The “on the go” solution is characterized by allowing easy access between the nurses offshore and the medical experts onshore to their common collaboration space for sharing medical information “on the go” and by flexibility in their decision-making process. The “on the go” solution is characterized by the ability to allow all involved roles in the decision-making process to be synchronized and interactive anywhere within minutes.

The collaborative work space “Virtual Examination Room – on the go” was developed and successfully tested in real cases between Ekofisk Offshore Hospital and St. Olavs University Hospital in Trondheim including the doctor on duty in Stavanger.

The major benefits with the Virtual Examination Room (VER):

- Access to all medical information in one system independent of location
- Improves collaboration, documentation and decisions by shared workspace
- Transparency and easier and safer collaboration room - improves HSE & QA
- Spend no time running after information and distributing of medical data
- Management dashboard gives top level overview
- Audit log gives participants better overview of what has happened [detail log]
- Easy access to experienced personnel on specific areas
- Spend less time on coordinating resources
- Faster response and more qualified response
- Better and safer decisions for improved health care

The “Virtual Examination Room – on the go” concept will be taken further into a next step spin-off project collaboration between St. Olavs University Hospital, IBM and oil companies.
Valuation of Integrated Operations

The project objective was to document the economic value of IO implementation at project level and corporate level. The main tasks were to understand and describe uncertainty aspects by identifying drivers of value creation in an IO-project as well as by identifying the risk factors that may prevent value creation and undesired situations. The resulted framework (Figure 1) focused on the value of smarter decisions and better execution: value of information (improving probability), value of control (improved outcome), value of flexibility (changed decision scope), and value of efficiency (faster decisions). The framework had been successfully verified in several industrial use cases assessing the value of both tangible and intangible benefits for finished and undergoing IO projects both in green-fields and brown-fields.

![Figure 1 - IO Value framework](image)

Key learned lessons and recommendations

The framework was developed and validated in two industrial case studies with IO Center partners operating on the Norwegian Continental Shelf: “Valuation of integrated planning” with ConocoPhillips and “Valuation of integrated drilling” with TOTAL E&P.

We found the framework to be an efficient tool to evaluate projects implementing IO not only with regards to economic value, but also to gain deeper insights into determinants and uncertainties related to value. We can conclude that the strength of the framework is a methodological process to analyse changes in competencies and capture downside risk reduction by IO.

Major lessons learned:
- The study of changes in intangibles and scenario extraction was found useful to the company and indicated the relevant changes, i.e. exclude changes resulting from other improvement projects;
- The qualitative questionnaire to analyse intangibles in all cases correctly captured shifts in the companies’ competencies;
- The framework can be efficiently applied in an organization and the process in itself of economic value is useful.

The IO Value framework was applied and further developed by Petrobras in a study of economic value creation by implementing Integrated Operations in Santos Basin.

Publication of the framework has received the best paper award at Business Information Systems conference (2009) and the Petrobras study has been acknowledged by the Brazilian Society of Production Engineering Award in 2014.
The IO Center has investigated cross-over technologies between different industries and specifically what the oil and gas industry can learn from military, medicine and aviation. The real time aspect of decision and execution made in collaborative environments are central in IO and in this study. We used a stack model and capability approach to investigate common challenges across the selected industrial sectors and demonstrated potential learning for the oil and gas industry.

**Industrial cross-over**

There is a wide interest in the oil and gas industry concerning potential opportunities for learning from other industries and sectors. The stack model including capabilities in the different layers is a central one in IO and points out the interdependencies that need to be managed across many levels and areas to achieve high levels of performance.

The factors that impact on performance are interconnected, i.e., they cannot be treated in isolation. The sectors of aviation, military, and medicine were chosen as they are faced with many similar challenges to those in the oil and gas industry regarding information overload, human factors, safety critical contexts and model based real-time decision making in complex technical systems.

We used a common stack model to compare the similarities between the industries including the decision and execution layer at the very top. The ability to achieve faster and better decision-making and execution depends on the layers below and the interdependency (interconnectedness) between the layers.

**Oil & gas Industry**

In the offshore petroleum industry the IO focus is about teams spread out at different geographical locations i.e. offshore operators and onshore located experts in order to exploit the underground reservoirs.

The oil and gas offshore operations are a very complex management and execution case where several disciplines within the oil company are contributing to the long term reservoir management along with the daily operations. The teams offshore and onshore are working together in integrated teams and are interlinked in video meetings daily. The oil companies also hires several supply companies to perform services together with their own organization making the operations even more complex from a team perspective.

The work process integration is supported by modern IO capabilities and organized according to our stack model. The decision and execution at the top is relying on the integrated data capture and information access, intelligent information work spaces and the collaborative work arenas.
**Military**

A main focus of military operations is running very complex and time critical operations where the surrounding environment is changing in way that is often hard to predict i.e., a large set of different military units are on high risk missions into the unknown. Integrated operations and decision support in real time, stack model and capability approach are of vital importance. These aspects have been refined in the military over decades and centuries, and there is a good potential for bringing value from the military context to other industries like the oil and gas sector. We focused in our study on reviewing network-centric warfare/operations and training and described these with reference to the stack model.

The figure illustrates the complexity of a military operation, and clearly shows a number of similarities with operations in the oil & gas sector. There are many operators in the field communicating closely with highly specialized people in operating centers via e.g. satellite communication. There are also links to stake holders in other countries and continents. Training is a specific topic that is extremely important for military operators in order to quickly discarding non-vital information, getting a good overview of important factors, and making the right decisions in due time.

**Aviation**

Air Traffic Management System (ATM) is about the process, procedures and resources which come into play to make sure that aircraft are safely guided in the skies and on the ground. Large amounts of information must be filtered, processed, trended and presented to a relatively small number of people in key decision-making roles. These roles involve significant responsibilities and the people executing these roles must be able to respond rapidly and optimally when non-routine situations arise. Many developments are currently underway in a wide range of topics relevant to IO Survey across Sectors.

In general, a reduction in the total amount of information presented to the human beings in such key roles necessitates a work process for analyzing the key decisions required, and what is needed to support those decisions.

Many operations may become automated to minimize the information load on the people involved. Incidents and accidents have revealed the importance of pilots understanding exactly the logic for how such automated processes are executed.

**Common IO challenges across sectors**

In all the different industrial sectors examined in the IO Survey Across Sectors project, a large amount of information is 1) gathered, 2) processed (including some modeling, prediction and optimization) and 3) presented (usually on a screen) to a group of people responsible for the “supervision & control”, and 4) decision and safe execution. Military and aviation are in the forefront. There is a strong learning and cross-over opportunity between medicine, military, aviation and oil & gas.
Future prospects

Integrated Operations is as important, or even more important, today as when the IO Center was launched in 2007.

With the current low oil price operators and service companies are forced to work smarter and more efficiently at a lower cost. Exploration, field development, and production of hydrocarbons are moving farther north, into deeper water, into more remote locations and harsher physical environments. Health, safety, and environment plays an even larger role than in traditional hydrocarbon development, and there is a need for new and better technologies, new models for operation, a deeper understanding and scientific knowledge of the operational environment and the interplay of all these factors.

Enabled by the Research Council of Norway the partners in the IO Center have built a world leading research environment within IO that will continue beyond the CRI period. The strong international network within practice and science is probably one of the most valuable results of this center. The research partners will continue as a center for research, development and innovation targeted at IO in the petroleum industry, and will collaborate closely both with companies that have been partners in the IO Center and new companies to take on the current and upcoming challenges for the future.

Some areas for current and future projects are:

- IO in field development
- IO in harsh and remote environments
- Scaling and global implementation of IO
- IO across sectors and industries

The IO Center has a large number of associated projects initiated as a result of the center, mostly bilateral projects but also joint industry projects. New collaborations both academically and industrially are arising in areas as Newfoundland of Canada and Santos of Brazil, where the IO Center research partners will contribute in building capacity in IO. A program for continued education within IO is also established, providing the latest insight.
Conclusions

The IO Center is a success and has through the 8 year CRI period developed into a world-leading environment for industrial-academic research and development on Integrated Operations. Behind this development a number of factors have been of great importance:

- Long-term funding from the Research Council of Norway on a topic of national and international interest, attracting industry partners and leading research institutions to come together and focus on a shared topic for longer period
- Industrial contributions from major oil and gas companies and leading service companies providing funding, competence and pilots
- Triangel model of collaboration between research institutions, oil and gas companies and service companies to develop industry relevant and commercializable solutions
- Complementary research partners from Norway coupled with world-leading research groups from universities from Europe and the Americas in a wide range of disciplines: sociology, product design, petroleum engineering, engineering cybernetics, HSE, logistics, linguistics, ICT, medicine, physics and much more
- A broad focus from education and inclusion of master students, development of PhD candidates, scientific publications, industrial reports and handbooks, pilot projects in operational settings, implementation of methods and software to innovation
- Strong focus on center building activities, dissemination and networking with many meeting arenas making a strong shared feeling between academia and industry
- The IO conference, showcasing the latest in industry practice and cutting edge research from the IO Center to a broad international audience

Integration of people, processes, technology and organization has been the focus of the center. The long term funding provided has enabled the activities in the IO Center both to go in depth into important challenges, and at the same time to be able to collaborate across areas and disciplines, and focus on the holistic picture. The partners in the IO Center have been able to gain deeper expertise in their own areas while also getting a more multi-disciplinary and cross-sectoral experience.

The center management has been focused, strategic and diplomatic, focusing on securing the success of the IO Center and on industrial application of research. This, together with a relatively clear project plan has secured a good working environment between institutions and researchers from different institutions in the center.

Active participation from all partners through such a long term project with many involved organizations and research programs can be challenging. Securing ownership to the center activities and connecting activities and research to internal processes and strategies of the partners is has been of great importance.

The IO Center has had strong focus on center building and connecting academia and industry closely. Every year two Board meetings with representatives from all partners have been held, two technical committee meetings with four representatives from all partners have been organized, in addition to a large number of seminars, workshops and project meetings. The center management has also frequently visited the partners. This has been important for securing industrial relevance of the research and closer ownership to the activities and results in the user partners' organizations.

The CRI program of the Research Council of Norway is an important funding vehicle that has enabled the establishment of a strong and long term research environment that has provided many scientific and industrial results, and that will continue to work together beyond the 8 year funding period.
### Appendix 1 - Funding and accounts

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All figures in kNOK
### Appendix 2 – Postdoctoral fellows, PhD candidates and MSc students

#### Postdoctoral researchers with financial support from the Centre budget

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#### PhD candidates who have completed with financial support from the center budget

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<td>Joint Optimization of Well Placement and Controls for Petroleum Field Development</td>
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<td>Interactional dynamics of team decision making A discourse analytic study of operational planning meetings in the petroleum industry</td>
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<td>Technical health, remaining useful life and life extension of subsea equipment</td>
<td>Marvin Rausand, NTNU</td>
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**PhD candidates who have completed with other financial support, but associated with the center**

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PhD students with financial support from the center budget who still are in the process of finishing degree

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MSC candidates with thesis related to the center research agenda and an advisor from the center staff

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<td>Robuste organisasjoner i integrete operasjoner</td>
<td>Jan Hovden, NTNU</td>
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<td>Ingrid Bouwer Utne, NTNU</td>
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<td>Helms, Per Olav</td>
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<td>Condition Monitoring as a driver for Logistics and Maintenance Planning</td>
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<td>Herdlevær, Vidar</td>
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<td>Houmstuen, Jørgen B.</td>
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<td>Condition Monitoring of Offshore O&amp;G Separator – Cost-Benefit Evaluations and Presentation of Information</td>
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<td>Huseynli, Pasha</td>
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<td>Evaluation of Polymer Flooding for Enhanced Oil Recovery in the Norne Field E-Segment</td>
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<td>Ragnheiður Karlsdóttir, NTNU</td>
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<td>Simulation study: combinations of surfactant injection and low salinity flooding on the Norne E-segment</td>
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<td>Abordagem Estratégica Orientada Para O Gerenciamento Integrado De Operações: O Caso Da Produção De Petróleo Do Pré-Sal Da Bacia De Santos</td>
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<td>A Comparative Simulation Study of Chemical EOR Methodologies (Alkaline, Surfactant and/or Polymer) Applied to Norne Field E-Segment</td>
<td>Jon Kleppe, NTNU</td>
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<td>Evaluation of Surfactant Flooding for EOR on the Norne Field, C-segment</td>
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<td>Assessing Weighting Coefficients in Seismic History Matching of the Norne Field</td>
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<td>History Matching and Uncertainty Assessment of the Norne Field E-Segment Using Petrel RE</td>
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<td>Correa, Celia</td>
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<td>Use of Functional Resonance Analysis Method (FRAM) as a tool to predict and identify future unwanted incidents</td>
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<td>The Planner in Practice : a case study of the Planner in Aker Solution s’ M&amp;M contract</td>
<td>Torild A.W. Oddane, HiST</td>
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<td>Risk in crane and lifting operations related to the logistic interaction process for well and drilling</td>
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<td>Dynamic Estimation for Controlling a Subsea Production System - Virtual Flow Metering using B-spline Surrogate Models</td>
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<td>Salberg, Ole Magnus</td>
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<td>Sandnes, Anders</td>
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<td>Addressing Dynamic Risk in the Petroleum Industry by Means of Innovative Analysis Solutions</td>
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<td>Simulation based optimization of petroleum production problems Development of a special purpose B&amp;B for a non-convex MINLP</td>
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<td>Lean Design Management in Aker Solutions Concept Studies: Set-Based Design, Last Responsible Moment,Target Value design, and Choosing by Advantages</td>
<td>Frode Olav Drevland, NTNU</td>
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<td>The Stratigraphic Method Applied to History Matching of the Norne Field</td>
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<td>Storvold, Vegard Svardien</td>
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<td>Optimization of investment decisions and production planning in aging offshore petroleum fields</td>
<td>Henrik Sangesland, NTNU</td>
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<td>Suman, Amit</td>
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<td>Uncertainties in rock pore compressibility and effects on seismic history matching</td>
<td>Tapan Mukerji, Stanford</td>
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<td>Szklarz, Slawomir Pawe</td>
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<td>History Matching via Ensemble Kalman Filter of Norne Field</td>
<td>Remund G. Hanea, TU Delft</td>
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<td>Risk modelling of collision between supply ships and oil- and gas installations</td>
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<td>Development of a field case with real production and 4D data from the Norne Field as a benchmark case for future reservoir simulation model testing</td>
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<td>The role of boundary objects in Virtual Design and Construction</td>
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<td>Emission Constrained Unit Commitment: Impacts of the Shale Gas Revolution</td>
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<td>History Matching of Production and 4D Seismic Data – Application to the Norne Field</td>
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<td>Yasin, Ilfi Binti Edward</td>
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<td>Pressure Transient Analysis Using Generated Well Test Data from Simulation of Selected Wells in Norne Field</td>
<td>Jon Kleppe, NTNU</td>
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Appendix 3 - List of publications

Books


Besnard, D., & Albrechtsen, E. (2013a). Lessons Learned and Recommendations from Section One Oil and Gas, Technology and Humans - Assessing the Human Factors of Technological Change.


Besnard, D., & Albrechtsen, E. (2013c). Lessons Learned and Recommendations from Section Two Oil and Gas, Technology and Humans - Assessing the Human Factors of Technological Change.


Journal articles


Conference proceedings


Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics (AHFIE).


Conference papers and presentations


Parmigiani, E. (2014). Of Corals and Web Portals: Towards a Digital Representation of Risk for the Cold-Water Corals in the


Ramstad L. S., Halvorsen K., Wahl A.M. Improved Coordination with Integrated Planning, Organisational Capabilities, SPE Intelligent Energy 2010, Networks 2010


Center for Integrated Operation in the petroleum industry

The IO Center was established in 2007 by leading international oil and gas companies, system suppliers, academic institutions and the Research Council of Norway, with the objective to undertake research, innovation and education on integrated operations.

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