ANNUAL REPORT 2019

BRU21

NTNU Research and Innovation Program in
Digital and Automation Solutions for the Oil and Gas Industry

NTNU

BRU21 vision

Enable higher efficiency, safety and reduced environmental footprint of oil and gas production through digital and automation technologies.

BRU21 mission

Mobilize multidisciplinary expertise across NTNU and, in cooperation with industrial partners, produce research results for novel technological and organizational solutions.

BRU21 goal

Deliver new knowledge, technologies, innovations and multidisciplinary specialists for the digital transformation of the Oil and Gas industry and for Norwegian society.

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Foreword

Egil Tjåland
Head of Department
of Geoscience
and Petroleum

The BRU21 research program at NTNU is set up for the ambitious goals of reducing costs and increasing profitability of oil and gas production by digital and automation solutions. The Covid-19 pandemic outbreak is a recent example of the unpredictable nature of oil demand and wild fluctuations in oil prices. The very basis for BRU21 was to do research that could lead to a leaner and more efficient way to explore, drill and produce oil and gas in addition to studying improved business plans and contract designs.

The current pandemic outbreak is a reminder that the original vision of BRU21 holds. We cannot control the oil price, but we can control production methods and costs.

Prof. Alexey Pavlov
BRU21 Program manager

BRU21 – NTNU's Research and Innovation Program in Digital and Automation Solutions for the Oil and Gas Industry – started in 2018. Yet its story began two years earlier, with a nationwide survey of the Norwegian oil and gas industry following the collapse of oil prices in 2014-2015. That survey, conducted by NTNU and called the BRU21 project, identified technological and research needs of the industry for oil prices as low as 30 USD/bbl. The survey led to a new NTNU strategy for oil and gas research and education, presented in the BRU21 report and at the BRU21 conference in May 2017.

Digital and automation technologies was the research area identified by the industrial actors as the most urgent need. That observation laid a foundation for establishing the BRU21 program – a multidisciplinary research program uniting NTNU experts, PhD candidates and industrial partners from both digital and petroleum domains, with the objective to meet the research needs in digital and automation technologies for the oil and gas industry. The program is also the first step in implementing the NTNU strategy in oil and gas research and education.

By the end of 2019, the program had grown to 33 projects, funded by 9 industrial sponsors and NTNU and run at 7 NTNU departments at 4 faculties. This report reflects the program's growth in 2019, including its initial phase in 2018.

BRU21 model

Multidisciplinary research on industrial use-cases

The abbreviation BRU21 stands for Better Resource Utilization in the 21st century. BRU21 is a multidisciplinary program uniting academic and industrial experts in Petroleum Engineering, Geoscience, Cybernetics, Robotics, Computer and Data Science, Cyber Security, Mechanical Engineering, Sociology, Management and Economics. The program focuses on creating impact across the oil and gas value chain through the generation of knowledge, novel digital and automation technologies, and organizational solutions, innovation and development of future digital-enabled specialists for the oil and gas industry.

The BRU21 program is built upon several key ideas. They result from thorough analysis of the needs of the Norwegian oil and gas industry (see the BRU21 report at www.ntnu.edu/bru21), as well as from prior experience in large projects and centres focusing on oil and gas research (e.g. IO Centre, Drillwell and SUBPRO).

PhD-based research

BRU21 is centred around PhD and PostDoc research projects on concrete digitalization/automation-related challenges (use-cases) formulated by the industrial partners. These projects, funded by the industry, are matched with NTNU-funded projects focusing on applied and fundamental research questions.

Value-focused program organization

The ultimate objective for the BRU21 program is creating business impact (value) through research, innovation and development of specialists. The full value of digitalization in the oil and gas industry can only be unlocked by combining digital expertise with domain knowledge accumulated in petroleum disciplines. This concept and the focus on value creation in the BRU21 program results in the organization of the program in 6 Program Areas:

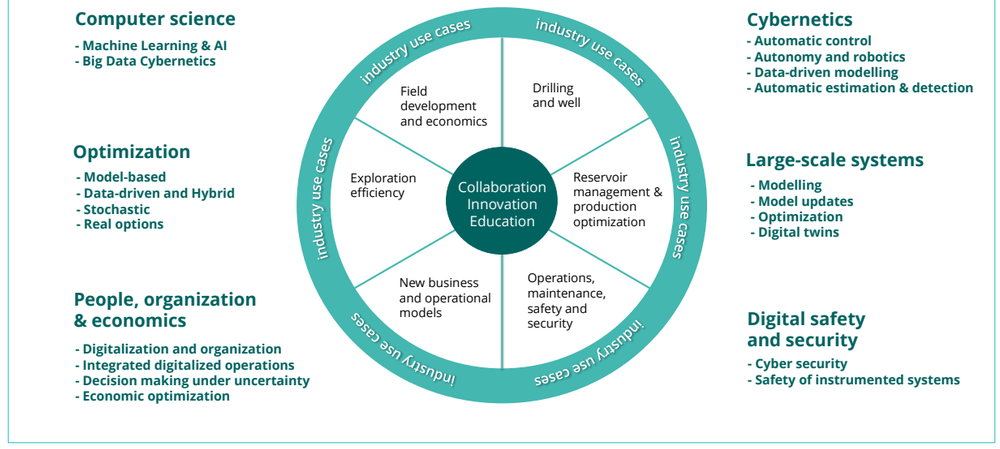
- Exploration efficiency
- Field development and economics
- Drilling and well
- Reservoir management and production optimization
- Operations, maintenance, safety and security
- New business and operational models.

Each program area consists of a number of PhD and PostDoc projects and covers a specific area of the upstream oil and gas value chain. Digital and automation expertise mobilized across NTNU forms a digital foundation for the whole program.

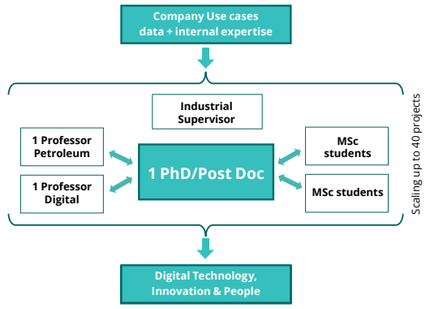
BRU21 project model

To facilitate multidisciplinary research, individual projects are supplied with two co-supervisors covering both digital and petroleum domains. In addition to that, industry-sponsored projects have industrial co-supervisors – experts from the sponsoring companies who serve as problem owners and gateways to their company's data and internal expertise. NTNU students working on MSc projects linked to BRU21 constitute the last element in the BRU21 project model.

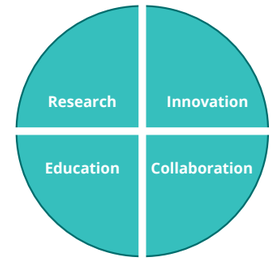
BRU21: Six Program areas + Digital foundation



BRU21 project model



BRU21 Ecosystem



Close collaboration with the industry

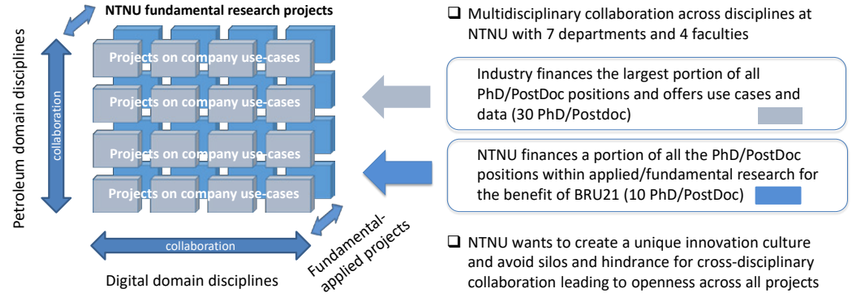
Collaboration with industrial partners goes across all levels of the program and all projects. The scope of the entire program is based on the industrial needs identified in the BRU21 report. Each industry-funded project focuses on an industrial use-case (practical challenge) provided by the company. Recruitment of PhD candidates often occurs with inputs from the sponsoring company. During the project, the industrial co-supervisor follows up the project from the company side and participates in the supervision. PhD candidates, PostDocs and MSc students work closely with the sponsor company and with company data.

BRU21 innovation model

New ideas often emerge on the boundaries between various disciplines and projects. The open collaboration culture that avoids silos is essential for creativity, innovation and efficient problem solving. In BRU21, collaboration occurs across digital and petroleum disciplines, and across program areas. In addition to industry-funded projects, the program has a number of NTNU-funded projects working on more fundamental research challenges related to digitalization and automation in the oil and gas industry. Interaction between this fundamental research and applied research on industry use-cases is another dimension of cross-collaboration in BRU21.

Open collaboration within the program is a vital part of BRU21. To facilitate this, NTNU retains ownership of project results, while providing the sponsor company with user rights for free use of the project results in all its internal operations. The precise conditions of BRU21 IP model are formulated in the BRU21 contract. By the end of an industry-funded project, the sponsor company also participates in defining a commercialization strategy for project results (e.g., licensing, start up company, open-source strategy).

BRU21 Innovation model: Cross-collaboration



Industrial partners

Value creation through collaboration

The key to success in the BRU21 Digital and Automation Program is the direct contact between the multidisciplinary academic team at NTNU and the O&G companies. Alignment of BRU21 with the objectives of digital transformation of the oil and gas industry and industrial relevance of its use-cases establish a firm foundation for successful BRU21-industry collaboration. The program is sponsored by 9 industrial partners and NTNU. Apart from companies operating in Norway, we have also established R&D cooperation with Petrobras in Brazil.

BRU21 program steering committee

Sponsor companies participate in the program at two levels: at the program level and the use-case level. Each sponsor company is represented in the BRU21 Program Steering Committee, which oversees the overall operation of the program and provides input to operational plans and directions for strategic development of the program.

BRU21 program steering committee meeting

The first Program Steering Committee meeting was held at NTNU on 17 October 2019. This was an important meeting with all our industrial partners. The BRU21 management team presented the status of the program, as well as analysis of future research possibilities within digitalization in the oil and gas industry (BRU21 Digital Update). The program received positive feedback from the Program Steering Committee on both the performance of the program and program development plans. In addition, the operation and strategic development of the program were discussed.

Collaboration at the project level

Each industry-sponsored research project is run on a company's use-case. The use-case is discussed and aligned between company experts and BRU21 professors to ensure both industrial relevance and a high academic level for the project. BRU21 forms a project team consisting of professors with relevant (multidisciplinary) expertise, PhD candidate or Postdoc, and an industrial co-supervisor from the company, who follows up the project as problem owner and facilitates access to data. MSc students are often recruited into the project team. They become attractive candidates for subsequent employment in the sponsor company.

BRU21 research projects are conducted in close collaboration with the sponsor companies, through regular meetings and interactions with company experts. This interaction is two-way. In the same way as company data and expertise goes into the project, research results from the BRU21 project reach the sponsor company organization on a continuous basis.

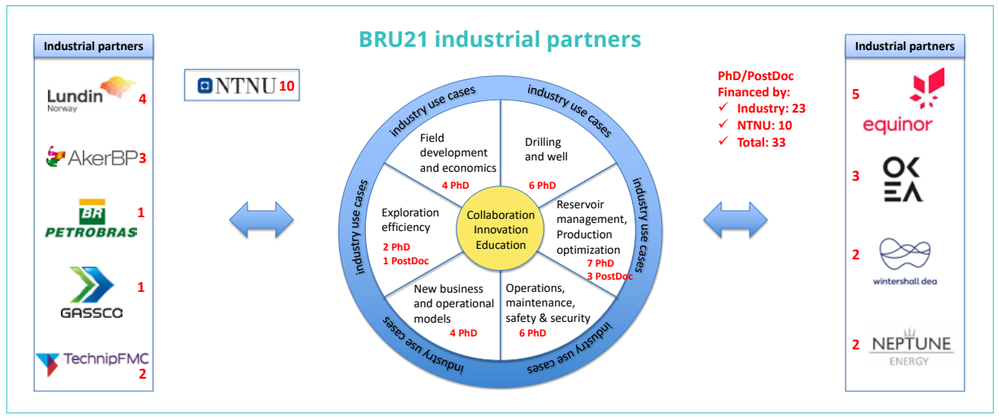
BRU21 industry meetings

The BRU21 program has worked systematically together with the industry to establish financing for PhD/Postdoc positions and to define relevant use-cases. Below is an overview of some key industry meetings held in 2018-2019.

Meeting with the Johan Sverdrup license team
On 11 December 2018, we had a very productive full day meeting and workshop with the Johan Sverdrup License team from Equinor chaired by Paal Frode Larsen. The program was set up in collaboration between Equinor and BRU21 and included both plenary and group discussions within "topside" and "subsurface" areas. Several topics were summarized for follow-up discussions.

Meeting with Equinor managers Arne Sigve Nylund and Kjetil Hove
We organized a half-day meeting at the Department of Geoscience and Petroleum for E&P Manager Arne Sigve Nylund and COO Kjetil Hove from Equinor on 7 May 2019. This was the most interesting and important meeting that gave us a unique opportunity to present the BRU21 Program for the top management for the Norwegian Continental Shelf in Equinor. BRU21 received very positive feedback. In the follow-up discussions with Equinor, two new projects were realized as a result of this meeting: "Risk-based maintenance" and "Remote operations & future operating models". The topics were in line with the discussion we had with the Johan Sverdrup license team.

Management meetings
We have had project meetings at management level with several of our industry partners to fine-tune projects and the use cases. Further, BRU21 maintains contact with many other O&G companies for future participation in the program.



BRU21 Program Steering Committee

Erlend Fjøsna
TechnipFMC

Kim Alexander Jørgensen
Lundin Norway

Danilo Colombo
Petrobras

Therese Rannem
Neptune Energy

Tor Ulleberg
Equinor

Qian Chai
AkerBP

Thomas Lerdahl
OKEA

Torgeir Norstad
Wintershall DEA

Britt Aarhus
Gassco

Egil Tjåland
BRU21 program owner, NTNU

Petrobras meetings and contract signing
NTNU has had over several years of R&D collaboration with Petrobras in the Center for Integrated Operations (IO Center) at the Department of Geoscience and Petroleum. This gave us a unique opportunity to discuss the possibility for collaboration on "digitalization and automation" topics and use-cases both from the Brazilian and Norwegian Continental Shelves. The contact was made jointly to the Petrobras operations at their headquarters as well as to the R&D Organization CENPES. We had meetings both in Trondheim and in Rio de Janeiro. The final contract was prepared during a Petrobras visit to NTNU in October and signed at Petrobras in Rio de Janeiro on 12 November 2019.

Statements from BRU21 industrial partners

AkerBP: Qian Chai
Predictive Maintenance Manager, Reliability & Maintenance

Aker BPs ambition is to build the leading independent E&P company and digitalization is a core ingredient in the strategy. Our digital vision is to digitize the value chain from exploration to abandonment. With a strong engagement from owners and top management, Aker BP established our own digital program Eureka. This digitalization lab is a unique arena for development and research in the new technology applications, such as the use of artificial intelligence and Big data to predict equipment failures and increase the output of oil and gas.

The BRU21 program provides Aker BP with a good opportunity to join the high-level interdisciplinary research at NTNU and have close collaboration with other O&G companies. Aker BP is engaged in three topics: Maintenance in remote operations, Petrophysics database for machine learning, and Zero emission in field development. These topics are well aligned with our Field of the Future concept for the new field development. The BRU21 program contributes to develop digitalization talent who will support the O&G industry's digital vision and expand the industry's future growth capacity.

OKEA: Thomas Lerdahl
VP Reservoir Development

OKEA has supported the BRU21 programme at NTNU since it was initiated in 2018. The technical focus on digitalization and automation addresses important opportunities for the oil and gas industry. Our two use-cases were defined on the background of actual problems that we are facing in development projects and operations. The research work is carried out in close collaboration between us, the PhD candidates, and their supervisors at NTNU. The results from these projects are therefore expected to directly add value to our business.

In addition to addressing highly relevant topics, the BRU21 program has a strong focus on education. This has allowed us to attract highly skilled, young professionals, whom we are proud to support, inspire and collaborate with.

Equinor: Tor Ulleberg
Senior Advisor Innovation and Collaboration

We regard BRU21 as an innovative and exciting model for collaboration between the industry and NTNU. We participate in educating the next generation of petroleum technologists with digitalization «under their skin» on top of addressing critical challenges for the future.

Digitalization is a necessary enabler inherent in most future value creation. Our fields of interest range from subsurface technology to risk-based maintenance, remote operations, future operation models and cyber security. Through our participation in BRU21 we contribute to competence development and innovation and thus high value creation in the future.

Lundin Norway: Kim Alexander Jørgensen
Manager, Operations Technologies and Work Processes in Technical Support.

Technology and digital solutions enable efficiency improvements throughout our supply and value chains. Changes in the way we interact with technology, how we cooperate as humans, how we consume information are evident in all aspects of society. The oil and gas industry represents a complex system of highly specialized technologies and work processes, and automation and high-tech solutions are widely explored and utilized. However, new capacities coming from connectivity, data storage capacity and processing power represent new opportunities. Exploring how digital technology can create additional value through increased efficiency and resource utilization is the reason why Lundin Norway is promoting the BRU21 program.

As an operator, Lundin Norway is dedicated to developing and employing cutting edge technologies through active participation in research and development programs, especially with focus on solutions and technologies addressing safety implications, energy efficiency and the environmental impact of the oil and gas industry.

BRU21 governance structure

Program owner
Egil Tjåland

Program Steering Committee

TechnipFMC, AkerBP, OKEA, NTNU, GASSCO, equinor, BR PETROBRAS, Lundin Norway, wintershall dea, NEPTUNE ENERGY

Coordinator industrial relations
Arild Nystad

Program manager
Alexey Pavlov

NTNU administrative support team

Program areas

Exploration efficiency	Field development and economics	Drilling and well	Reservoir management and production optimization	Operations, maintenance, safety and security	New business and operational models
					
Prog. area manager Kenneth Duffaut	**Prog. area manager** Milan Stanko	**Prog. area manager** Sigbjørn Sangesland	**Prog. area manager** Lars Imsland	**Prog. area manager** Jørn Vatn	**Prog. area manager** Per Morten Schiefloe
Co-manager Carl Fredrik Berg	**Co-manager** Verena Hagspiel	**Co-manager** Alexey Pavlov	**Co-manager** Carl Fredrik Berg	**Co-manager** Mary Ann Lundteigen	**Co-manager** Eric Monteiro

BRU21 research projects at host NTNU departments

- Department of Geoscience and Petroleum
- Department of Engineering Cybernetics
- Department of Computer Science
- Department of Information Security and Communication Technology
- Department of Mechanical and Industrial Engineering
- Department of Sociology and Political Science
- Department of Industrial Economics and Technology Management

BRU21 projects portfolio

Projects and sponsors

Exploration efficiency

- Automated seismic reconstruction of missing sections (Neptune Energy)
- The impact of well data quality on machine learning performance (AkerBP)
- Automated facies classification through applying machine-learning to pre-stack seismic data (Wintershall DEA)

Reservoir management and production optimization

- A hybrid data-driven and mechanistic model for production optimization in the oil and gas industry (Lundin Norway)
- Optimization across time scales in oil and gas production (NTNU)
- Data-driven control and optimization of oil and gas production systems (NTNU)
- Assisted history matching for petroleum reservoirs (Equinor)
- Automated lithology classification employing whole core CT scans (Equinor)
- Assisted history matching, reservoir model update and optimization (Equinor)
- Production optimization strategies for offshore production systems with water processing constraints (OKEA)
- Improved technology for production optimization, with focus on gas lift allocation (Wintershall DEA)
- Data-driven reservoir modelling (NTNU)
- Integrated Reservoir Tool: FieldOpt (NTNU)

Field development and economics

- Improved planning methods for more energy efficient and environmentally friendly fields in the Barents Sea (AkerBP)
- Cost effective development of small discoveries on the NCS (OKEA)
- Automated methodologies for decision support in field development (Lundin Norway)
- Short-term optimization under uncertainty in the Norwegian natural gas system* (Gassco)

Operations, maintenance, safety and security

- Maintenance optimization in remote operations (AkerBP)
- Predictive maintenance (Lundin Norway)
- Industry 4.0 and smart predictive maintenance (NTNU)
- Safety and security in design and operation of ICS systems (NTNU)
- Predictive maintenance and remaining useful lifetime* (OKEA)
- Risk based maintenance* (Equinor)

Drilling and well

- Digitalization/automation of life-cycle well integrity (NTNU)
- Safe drilling in karstified carbonates (Lundin Norway)
- Automatic real-time surveilance of drill-string vibrations (NTNU)
- Drilling data analytics (NTNU)
- Intelligent data analytics for offshore well integrity and life cycle management* (Petrobras)
- Real-time fault and symptoms detection in drilling operations with wired pipe* (NTNU)

New business and operational models

- Digital relations and new business models (TechnipFMC)
- Collaboration and digital tools in early stage design of offshore facilities (TechnipFMC)
- From idea to discovery: information sharing and cooperation in the exploration value chain* (Neptune Energy)
- Remote operations and future operating models* (Equinor)

** - project to be started in 2020*

BRU21 PROGRAM AREAS

PA1. Exploration efficiency

PA2. Field development and economics

PA3. Drilling and well

PA4. Reservoir management and production optimization

PA5. Operations, maintenance, safety and security

PA6. New business and operational models

Exploration efficiency

Prototyping future geoscience data organization and analytics tools for improved exploration workflows

Geoscience workflows applied in hydrocarbon exploration cover the acquisition, processing and interpretation of vast amounts data e.g. seismic and wellbore data (Big Data). These are extensive, time-consuming and costly processes. Most of these workflows are expert-driven, with geoscientists being closely involved in data interpretation, providing inputs to high level investment decisions.

The rapidly growing amount of available data (the ever-increasing amounts of log data, multiple measurements of a single parameter, higher resolution data, etc.) and the reduced time allocated for its analysis and high-confidence decision making, make these tasks even more challenging and call for new methods. Development of fully- or partly automated methods, data-driven methods like machine or deep learning, in combination with rapidly increasing computational power open novel opportunities for the geoscience community.

Challenges and opportunities

The oil and gas industry is acquiring an ever-increasing amount of costly subsurface data, both at the earth's surface, through seismic (2D or 3D) and repeated seismic (4D) surveying, and in wellbores, where thousands of drilling and wireline logs are acquired. The amount of acquired data in, for example, drilling and wireline logs is nowadays far beyond the current standard from the NPD's "Blue book". Fast and efficient processing and interpretation of these vast amounts of data is still a challenge. This is partly because the geoscience workflows are still highly manual and, hence, limited by geoscientists' capacity to digest and analyze data. The other challenge is related to time/effort needed to access all acquired and processed seismic and wellbore data, which are vast, heterogeneous, are not well structured, and require quality control and subsequent corrections.

To address these challenges, one can leverage recent developments in computational power and data analytics methods, including methods like machine learning. These kinds of tools can explore hidden connections among different physical quantities through automated analysis of all acquired field measurements, seismic and wellbore data. Like any other automated technologies, these methods require high data quality and a data infrastructure that is optimized for their use.

Automated methods for data quality control as well as data organization suitable for streamlined application of data-driven/machine learning algorithms are prerequisites for automating the current geoscience workflows or even for completely replacing them with more efficient workflows enabled by machine learning tools.

Achieving the ambition of digitalized workflows will require intelligent integration of, and easy access to "all" available subsurface data: well logs, drilling data, laboratory data, all kinds of meta data and geophysical field data, e.g. surface seismic. It is especially in the storage of drilling and wireline log data where better data organization, easy access, automated data quality control and tracking updates of metadata associated with each single log measurement can lead to significant value creation.

Replacing humans by machine-learning algorithms in an expert-driven workflow is of course very difficult, since the experience and knowledge of geoscientists will always be a crucial ingredient in the geoscience workflows. However, seamless and easier access to all acquired data in combination with the utilization of machine learning-based approaches and fully automatic low-level subsurface data analysis may deliver high confidence results with enough speed and precision to make the exploration and production assets more efficient. If successful, the new data-driven workflows may release new opportunities in terms of more complete and comprehensive data analysis and, not least, may release the creativity and capacity of geologists and geophysicists towards solving new or more complicated subsurface challenges.

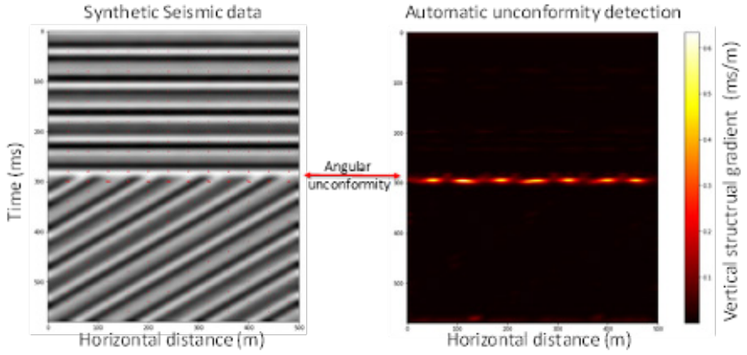


Figure 1: *2D Synthetic seismic images without noise (left) and its corresponding processed normal vector image displaying the location of the respective angular unconformity (right).*

Program area team

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Ammar Ghanim
PhD candidate

Luc Alberts
PostDoc

Yngve B. Johansen
AkerBP

Therese Rannem
Neptune Energy

Carl Jörg Petersen
Wintershall DEA

Research strategy

The BRU21 program area "Exploration Efficiency" focuses on the following main research directions:

1. Data organization: Establish the fundaments for new well databases with easy access for a machine learning code.
2. Automatic data quality analysis: Develop algorithms for automatic/automated quality assessment and pre-processing of geoscience data.
3. Data analytics: Develop data analytics methods for both well and seismic data in the quest to automatically detect and classify features within the data sets. This will be tried both with supervised and unsupervised machine learning methods. Precision and accuracy metrics are to be developed to check and control performance of the individual methods.

Current phd and postdoc projects

Automated seismic reconstruction of missing sections
PostDoc: Luc Alberts, Main supervisor: Keneth Duffaut, Sponsor: Neptune Energy

The project deals with designing and implementing software algorithms that automatically detect and trace geological unconformities typically found within seismic data sets, and label these before reconstructing the surfaces that have undergone uplift and erosion, see Figure 1.

The impact of well data quality on machine learning performance
PhD candidate: Veronica Alejandra Torres Caceres, Main supervisor: Kenneth Duffaut, Sponsor: AkerBP

The project focuses on two topics: 1) Prototyping the "future" well database that integrates "all" measurements acquired in wells together with their corresponding meta-data; 2) applying and training machine learning algorithms to automatically access data quality, depth shifting, rock typing, similarity recognition, as well as estimate petrophysical and geophysical parameters, see Figure 2.

Automated facies classification through applying machine-learning methods to pre-stack seismic data analysis
PhD candidate: Ammar Ghanim, Main Supervisor: Kenneth Duffaut, Sponsor: Wintershall DEA.

This project addresses the following topics: 1) automatic grouping of lithology into classes through combining rock physics templates with wireline data; 2) development of an automated seismic wavelet estimation technique; 3) generation of a synthetic pre-stack response catalogue through use of linearized amplitude versus angle expressions and machine learning-based approaches to cluster seismic amplitude responses into subsurface lithology classes.

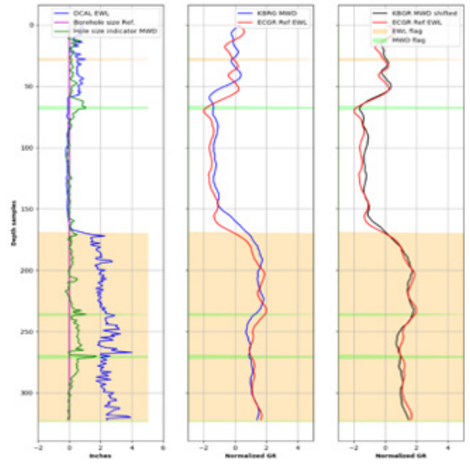


Figure 2: *Automatic depth matching of Gamma Ray logs from MWD and electric wireline (EWL) before and after depth shift correction.*

Field development and economics

Better field planning methods and economic strategies through digital technologies and digitally enabled work processes

A proper field development plan is an essential component for exploiting new resources on the NCS in a profitable, efficient, safe and environmentally friendly manner. The goal is to define a detailed execution plan, timeframe, requirements and costs, contract framework, among others, to maximize the economic value to the stakeholders while producing the resources in a safe and environmentally responsible manner. However, this is extremely challenging because the data available is limited and uncertain, the time available for evaluation is often short and there are several socio-economic, political and regulatory constraints to honor. Moreover, the future operation, performance and success of the field depends on devising an optimal field development concept capable of counterbalancing varying conditions and unexpected events during execution and operation.

Challenges and opportunities

There are several important challenges during the development of oil and gas fields that must be taken into account such as volatile and low hydrocarbon prices, cost overrun, reservoirs of marginal size, adoption and assimilation of new technologies, quantifying and decision making under uncertainty, improving the field's environmental performance, projects in remote, sensitive and harsh locations, among many other factors.

Nowadays, there are several rapid-moving advances and progress in the fields of machine learning, artificial intelligence, data analytics, digital twins that have considerable potential to improve existing work processes if understood and assimilated properly. Also, there are other more mature technologies such as automatic control and optimization, mobile robotics, remote operations, stochastic analysis, which have a proven track-record of success in other industries, but which are not yet fully adopted by the oil and gas sector.

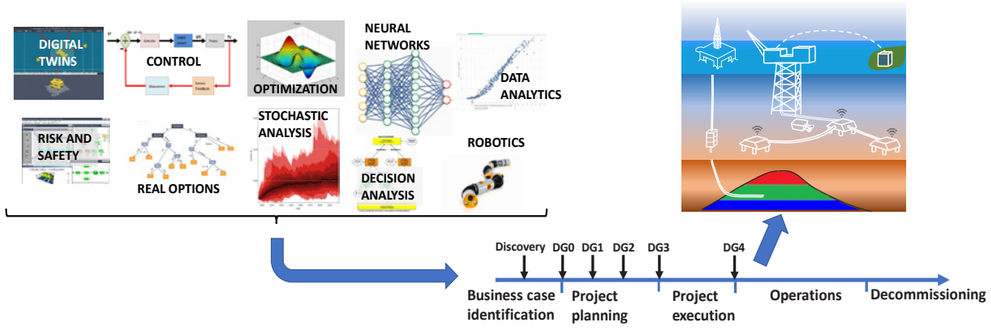
Research strategy

The goal of the field development and economics research area is to tackle the challenges mentioned above, and ultimately develop (digital) solutions that can improve field development workflows and be successfully assimilated by the industry. Simply put, the primary focus is on developing, testing and quantifying methods to gather, analyze, process, filter and study information, as well as on efficient decision making based on available information.

The ambition is to fully exploit the advantage of digital and automation solutions, traditional and recent, to improve and ultimately make a step change in the planning and development of oil and gas fields. We start with mature and well-known knowledge and methods, understand their advantages and limitations and devise strategies for further development. Newer trends and methods will also be studied and explored to determine their potential value and applicability for field development, followed by eventual further development. In this way we aim to combine the best of mature and novel methods to maximize usefulness, reduce user complexity and enhance robustness, scalability and sustainability.

Relevant methods to consider, evaluate and expand further in our research are: integration of heterogeneous models, development of large-scale digital twins, optimization and control at different time scales, stochastic analysis, risk and safety analyses, decision making theory, robotics, data analytics, real options, machine learning and artificial intelligence , blockchain and digital organizational theory. Expected outcomes of the research are better field planning methods and development strategies fully or partly based on digitally enabled work processes and digital technologies. This includes methods to:

- Integrate efficiently and timely uncertain and heterogeneous information for digitally enabled work processes and digital technologies within field development.
- Determine when is it worthwhile to acquire more information in different stages of field development.
- Automatically detect and flag critical project drivers and the most important factors.
- Take optimal field planning decisions.
- Consider, evaluate and follow-up the use of novel and unproven technologies in a hydrocarbon field.



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PhD candidate


Seok Ki Moon
PhD candidate


Thomas Lerdahl
OKEA


Arnljot Skogvang
Lundin


Tom Widerøe
Lundin


Kjetil Aasoldsen
AKerBP


Nina Aas
AKerBP

Current PhD projects

Improved planning methods for more energy efficient and environmentally friendly fields in the Barents Sea
PhD candidate: Seok Ki Moon, Main supervisor: Milan Stanko, Sponsor: AkerBP

This project studies field planning methods to develop offshore fields with a small environmental footprint, increased energy efficiency and reduced emissions. The focus is on 1) improving understanding of environmental KPIs and how are they influenced by field design features; 2) development of a digital twin of the field study case to predict emissions, energy usage and efficiency of the field; 3) development of computational routines for decision support; 4) study of alternative economic valuation methodologies to include environmental factors.

Cost effective development of small discoveries on the Norwegian Continental Shelf
PhD candidate: Semyon Fedorov, Main supervisor: Verena Hagspiel, Sponsor: OKEA

This project studies field development methods for reservoirs of modest to small size, with prominent downside risk. The project focuses on 1) the value of flexibility for field development by combining the real options approach and decision analysis; 2) comparing these advanced valuation methods against traditional methods; 3) assessing the value of acquiring additional information on the reservoir to execute improved oil recovery projects during the production phase; 4) study of a staged-development design philosophy.

Automated methodologies for decision support in field development
PhD candidate: Guowen Lei, Main supervisor: Milan Stanko, Sponsor: Lundin

The aim of this project is to develop computer-based robust and reproducible methodologies that advise field planners in defining the main features of the field in phases DG0-DG2. This will be performed by 1) developing a digital twin of the field's value chain, 2) developing machine-learning based models and integrating models of various nature and complexity, 3) developing and testing methodologies (e.g. optimization, probabilistic simulations) to determine optimum design features, 4) analyzing uncertainty and energy usage, CO2 emissions, ease of decommissioning.

Project to be started in 2020

Short-term optimization under uncertainty in the Norwegian natural gas system
PhD candidate: to be hired, Main supervisor: Asgeir Tomasgard, Sponsor: Gassco.

This project will address developing models and solution methods for short-term optimization of linepack and compressor management focusing on trade-offs between energy efficiency, CO2 emissions and economic values of flexibility. In addition to new models, this requires advanced optimization techniques and development of these. The project will study a combination of model-based and data-driven control and optimization to dynamically manage faults detection and responses.

Drilling and well

Digital and automation solutions for reduced cost, environmental footprint and increased safety of Drilling and Well operations

Approximately 50% of field development costs are related to offshore drilling and well activities, and 80% of offshore well cost is time related. Thus, the high cost of well drilling and construction is perceived as important by oil companies. The expected answer to this, by the same actors, is increased autonomy of drilling operations through automation and extensive use of data- and digital technologies for optimization of drilling and completion operations.

Challenges and opportunities

The main challenges in D&W are time consuming well planning, high Non-Productive Time (NPT), high time-related costs, environmental footprint (especially time-related), inaccurate/insufficient measurements and challenging interpretation of the drilling data (both downhole and topside), high uncertainty about underground conditions and decision making under such uncertainty.

Current digitalization and automation solutions adopted by the industry include model-based planning and optimization, monitoring and low-level automation systems, as well as human experts support (e.g. in remote support centers) with their expertise/experience and simulation software support, as shown in the figure below. Recent developments in Data analytics, Autonomy, Automation and Remote operation, Digital twins as well as Digitalized organization open significant opportunities for further improvements in efficiency, safety and reduced environmental footprint in D&W operations.

Research strategy

There are five research directions within digitalization and automation in D&W pursued in this program area.

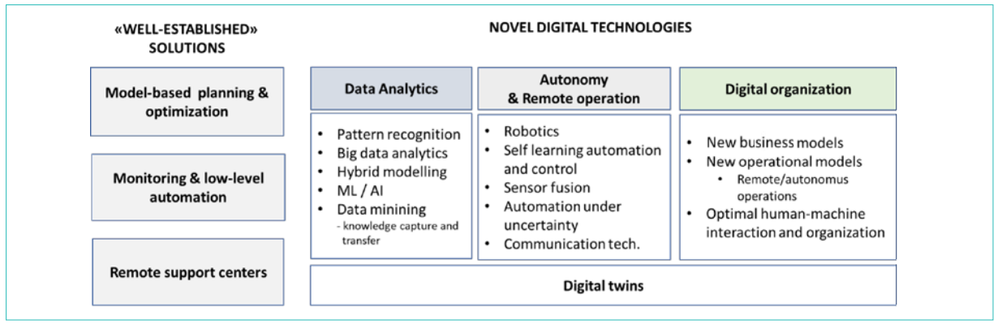
Digital well planning: Well planning today is a lengthy process that includes manual iterative use of a number of models and programs for the design of the well path, hydraulic pressure loss, etc. There is considerable potential for improvement in this area, for example, by integrating this process in a digital twin-like service combining all the models and experience from prior operations.

Automated operations: In recent years we have witnessed increased automation of single functions, such as automated operational limits, automatic well guards, automatic sequences, as well as a certain level of automatic process control as, for example, in MPD technology. Larger gains can be expected when building integrated systems that automate across these functions to achieve higher-level performance.

Decision support systems: Increased efficiency and safety can be achieved by automating and integrating data analytics into decision making processes in drilling and completion operations. The driller and support personnel may then focus on higher supervision-level tasks that cannot be performed by machines. For increasing streams of real-time and logged data (e.g., with the use of wired drill pipe), automated data analytics and decision support systems become a necessity.

Novel measurement methods: Data is the key component for data analytics, decision making and automation systems. Measurements data can be acquired through passive sensing from downhole and top-side sensors during ongoing operations. It can also result from active information "harvesting" as in well- and equipment testing. Both passive and active data gathering are far from exhausting their potential benefits from digital and automation technologies.

Integrated digitalized operations: For safe and efficient D&W operations, one needs to address digitalization and automation (including various levels of remote operations) not only from the technology point of view, but also from the organizational perspective that considers the human factor in the interaction between people and digital technologies. Cyber security, safety of instrumented systems, human-machine interaction, and new operational models will play an essential role here.



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Current PhD projects

Digitalization / automation of life-cycle well integrity
PhD candidate: Andreas Teigland, Main supervisor: Sigbjørn Sangesland, Sponsor: NTNU

The main objective of this project is to build a model for predictive real-time casing wear estimation. Automating the procedure of recalibrating the simulations with real-time data continuously during operation is stage one of the project. Secondly, an algorithm for wear mitigation though control of operational parameters will be developed. Expected output of the project is a prototype software for estimation and mitigation of casing wear.

Safe drilling in karstified carbonates
PhD candidate: Danil Maksimov, Main supervisor: Alexey Pavlov, Sponsor: Lundin

This project focuses on developing methods for detection and mitigation of risks while drilling in karstified carbonates. Drilling into a karst-like object can lead to losses of drilling fluid into the formation, including the most severe case of lost circulation. Detecting regions with high risks of karst-like objects or even predicting such objects in proximity of the drilling bit has a significant value for drilling safety. The project seeks such detection methods either based on available drilling data or based on novel measurement tools.

Automatic real-time surveillance of drill-string vibrations
PhD candidate: Ivan Pirir, Main supervisor: Sigve Hovda, Sponsor: NTNU

The project deals with development, simulation and optimization of dynamic models that can accurately predict the motion of a drill string during a drilling operation. The main focus is on models that are fast enough to be used with real-time data. Extending such models to include the hydraulics of drilling fluids also allows for the estimation of the bottom hole pressure changes. The expected outcome of the project includes partially validated models that can be used to estimate axial and torsional drill string vibrations and are also suitable for real-time implementations.

Drilling data analytics
PhD candidate: Magnus Nystad, Main supervisor: Alexey Pavlov, Sponsor: NTNU

The main objective of this project is the development and testing of data-based methods that automatically navigate the input variables of the drilling process (such as WOB, RPM, flow rate) to their optimal values in real time while adhering to constraints. The methodology is based on model-free automatic optimization methods that gather information about the current drilling situation through small variations in the input parameters and take optimization actions in accordance with the system response. The expected outcome of the project is an algorithm/prototype software to optimize drilling variables while adhering to operational constraints.

Projects to be started in 2020

Intelligent data analytics for offshore well integrity and life cycle management
PhD candidate: to be hired, Main supervisor: S. Sangesland, Sponsor: Petrobras

The objective of this project is to develop a system/method capable of monitoring and ensuring the functionality of the well safety barrier during all stages of its life cycle. The focus is on combined utilization of available models and (Big) data logged during prior drilling and well operations. The expected project outcome is an algorithm/prototype software for well condition monitoring and development of corresponding prototypes for the demonstration of the method.

Real-time fault and symptoms detection in drilling operations with wired pipe
PhD candidate: to be hired, Main supervisor: Behzad Elahifar, Sponsor: NTNU

The objective of this PhD project is to develop systems and methods to reduce drilling and well construction time. This includes improvements in safety. The main focus is on the utilization of wired drill pipe, which provides means for high-speed communication of real-time downhole measurements. These measurements provide the basis for (Big) data analytics tools for real-time decision support.

Reservoir management and production optimization

Modelling and optimization of reservoir and production systems – handling uncertainties and unlocking value with Big data and smart analytics

Once a petroleum asset is in production, strategies for reservoir management and production optimization are central in all field operations. The overarching goals of these strategies are to maximize the return value of investments in terms of recovery of hydrocarbon reserves. In addition, in later years, minimizing the environmental footprint of the activities is taking a more central place. It is also important to take into account the safety implications of reservoir management and production optimization decisions.

There is huge potential in taking a structured and analytical approach to reservoir management and production optimization. Analytical approaches refer to systematic processes to reach decisions based on a combination of models and data analytics.

Reservoir management and production optimization involves decision-making on several horizons, from the day-to-day decisions regarding choke settings, artificial lift, etc., to longer-term decisions regarding EOR rates and chemical additives, all the way to deciding new production and injection wells. Traditionally, responsibilities are divided between production engineers for the shorter-term decisions, and reservoir engineers for the longer-term decisions.

Challenges and opportunities

There are a multitude of challenges in decision-making for reservoir management and production optimization. The majority of these challenges are rooted in the large uncertainties related to reservoir properties and wellbore/pipeline flow. Most of these uncertainties are related to the limited information that is available regarding the subsurface, but there are also typically large uncertainties and/or noise in the data that are actually available. The uncertainty also has a timescale aspect to it, as indicated in the figure below.

The split in responsibilities between reservoir engineers and production engineers may imply that there is a considerable upside in handling the different timescales simultaneously. There is a need for improved and new tools and methods that help engineers handling these challenges.

Research strategy

The BRU21 approach to reservoir management and production optimization is based on these major digital/automation technology disciplines: Machine learning and hybrid (mixed data-driven and physics-based) modelling, optimization and decision-making systems, and autonomous systems and automatic control.

Some of the above-mentioned potential can be unlocked by production optimization tasks with short-term horizons, e.g. finding the optimum settings of well chokes and artificial lift. Finding these optimum settings requires not only understanding the reservoir potential through reservoir models, but also continuously leveraging on the information available in past and present production data. To be able to achieve this, machine learning from production data must be combined with physical reservoir and production network models through hybrid modelling to generate fit-for-purpose predictive analytics and optimization models.

Decision strategies for processes occurring deep in the reservoir are based on longer-term horizons and relatively sparse amounts of measured data. Simulation models for fluid flow in full field reservoirs are known for their high computational demand, and workflows for optimization of management

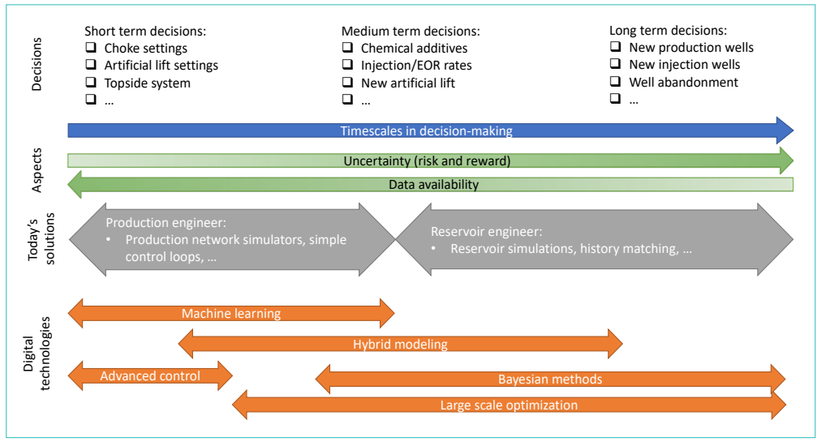

Figure: *Timescales, data availability and uncertainty scales in production optimization and reservoir management. Today's solutions and novel digital technologies.*

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strategies tend to be manual due to the complexity of the simulation models. This has left untapped opportunities in automated optimization of reservoir management tasks, e.g. long term well control settings and well placement.

Current PhD and postdoc projects

A hybrid data-driven and mechanistic model for production optimization in the oil and gas industry
PhD candidate: Mathilde Hotvedt, Main supervisor: Lars Imsland, Sponsor: Lundin

Hybrid modelling, also called grey-box modelling, combines the principles of two modelling approaches; physics-based, first-principle, mechanistic modelling and data-driven modelling. The idea is for the hybrid model to preserve the favorable characteristics of mechanistic models, such as physical interpretability and good extrapolation abilities, while exploiting the ability of data-driven models to capture unknown/unmodelled phenomena. In that manner, the hybrid model should have the potential to achieve high levels of accuracy and still be computationally feasible for utilization in real-time optimization.

Optimization across timescales in oil and gas production
PhD candidate: Joakim Rostrup Andersen, Main supervisor: Lars Imsland, Sponsor: NTNU

Some control and optimization problems face different objectives on different timescales, where the objectives may be in conflict. In this project we study efficient formulations and computational frameworks within the model predictive control (MPC) paradigm that handles both timescale issues and the multi-objective nature of these problems. An example of such a problem is production optimization in resource-constrained production. On a short term, one usually wants to optimize current production to maximize economic revenues. On a longer term, one may want to maximize the overall recovery of resources. Typically, some of the decision variables are common for the two objectives, but the objectives are not necessarily aligned: strategies that maximize current production may lead to non-optimal recovery. How to develop efficient computational tools for such multi-objective and multi -time-scale problems is the focus of this project.

Data-driven control and optimization of oil and gas production systems
PostDoc: Thiago Lima Silva, Main supervisor: Alexey Pavlov, Sponsor: NTNU

This project deals with data-driven control and optimization methodologies for oil- and gas production systems in different time scales. On a long-term scale, the proposed approach combines simulation models with data-driven optimization to deal with unavailable gradient information and parametric uncertainties. On a shorter time scale, the adopted approach is a data-driven automatic optimization method referred to as Extremum-Seeking Control (ESC), which allows one to achieve automatic optimization of steady-state behavior of an unknown plant. The methods developed in this project support a number of other BRU21 projects.

Assisted history matching for petroleum reservoirs
PhD candidate: Tarek Diaa-Eldeen, Main supervisor: Morten Hovd, Sponsor: Equinor

This research project aims at introducing and implementing novel methods to address the computational challenges in the ensemble-based History Matching (HM), with the purpose of reducing uncertainty in the model and, therefore, increasing the forecasting accuracy and production control efficiency. HM is the inverse modelling problem where an initial reservoir mathematical model is iteratively, manually or automatically, updated to match the production data. Ensemble methods in general, and particularly the Ensemble Kalman Filter (EnKF), have been widely used in HM problems. This research project is designed to introduce new and improve existing methods, such as the localization and covariance inflation, to enhance the EnKF's performance in HM problems.

Automated lithology classification employing whole core CT scans
PhD candidate: Kurdistan Chawshin, Main supervisor: Carl Fredrik Berg, Sponsor: Equinor

X-ray computerized tomography (CT) imaging is a non-destructive method for inspecting whole core samples that provides information on textural and compositional variations in reservoir rocks with a millimetre-scale resolution. Recent improvements in CT scanning and reconstruction, combined with developments in computing power and image analysis algorithms, have opened new possibilities for extracting more information from whole cores, and thereby increasing their value in operational settings. The main objective of this project is to develop routines and workflows to exploit the possibilities of whole core CT-scanning in combination with well log and core analysis data. It will address rock typing based on automated image analysis routines and will investigate the possibilities for machine learning procedures based on the CT image and well logs.

Assisted history matching, reservoir model update and optimization
PhD candidate: Brage Strand Kristoffersen, Main supervisor: Carl Fredrik Berg, Sponsor: Equinor

Optimization of wells in a reservoir is a time consuming effort. Reservoir uncertainties and structural challenges can result in the procedure providing suboptimal locations. This project investigates new types of parametrizations that, by replicating the decision-making process of geosteering, might enable a more efficient mapping of the search space. Features such as channels and faults can be dealt with and taken into account without increasing the complexity of the problem, yielding more realistic and productive well configurations.

Production optimization strategies for offshore production systems with water processing constraints
PhD candidate: Otávio Fonseca Ivo, Main supervisor: Lars Imsland, Sponsor: OKEA

Mature fields are responsible for producing 70-80% of oil and gas worldwide. Due to natural water encroachment or employment of recovery techniques, mature fields have an increasing water-cut that can reach values above 97%. For each barrel of produced water there are costs related to pumping, storage, treatment and management. Therefore, produced water is a critical issue in the oil and gas industry as it economically affects the field asset and is environmentally challenging to surroundings. To add economic value to produced water, reinjection of produced water for enhanced oil recovery (EOR) is generally employed. This project seeks to investigate energy saving control and optimization strategies for produced water reinjection.

Improved technology for production optimization, with focus on gas lift allocation
PostDoc: Mammad Mirzayev, Main supervisor: Lars Imsland, Sponsor: Wintershall DEA

Maximizing oil production from any reservoir depends on decisions made on several horizons. The scope of this project is to optimize production across these horizons, with particular emphasis on gas lift allocation. Making the right decision is a key to safe and efficient operation. The project will develop solutions that optimize the allocation of gas lift using a combination of simple models and data-driven methods.

Data-Driven Reservoir Modelling
PhD candidate: Cuthbert Shang Wui Ng, Main supervisor: Ashkan Jahanbani Ghahfarokhi, Sponsor: NTNU

Numerical reservoir simulations are widely applied to assist in decision-making related to reservoir management. However, more accurate models will need higher computation time. To mitigate this, a smart proxy model (SPM) has been developed. SPM applies a combination of advanced methods, such as optimization, statistics and data-driven techniques, which aim at significantly decreasing the run-time in any reservoir simulation task. The objective of this project is to improve the understanding of data-driven modelling and applying smart proxy modelling in reservoir simulations. The approach combines numerical simulations and data-driven techniques. Models are updated in real-time, creating realistic opportunities for real-time reservoir management in smart fields with uncertainty analysis.

Project to be started in 2020

Integrated reservoir tool: FieldOpt
PostDoc: to be hired, Main supervisor: Morten Hovd, Sponsor: NTNU

This project focuses on maintaining and further developing FieldOpt – NTNU's open-source software platform for development of simulation-based optimization methods. FieldOpt's main task is to codify, integrate and advance engineering expertise and optimization methodology to enhance educational, research and industry applications for efficient development and management of petroleum and other energy sources. FieldOpt provides extensive capabilities for prototyping, customization and real-case application of novel optimization routines coupled with state-of-the-art numerical simulators, e.g., models of subsurface fluid flow and upcoming renewable energy systems.

Operations, maintenance, safety and security

Digital and automation solutions for optimized maintenance, improved safety and reliability and higher security levels

The basis for the BRU21 program area on operation, maintenance, safety & security is the opportunities we see in light of the digitalization & automation taking place these days. Important aspects are predictive maintenance/real-time monitoring of asset condition, Big data analytics and artificial intelligence (AI)/machine learning (ML), as well as "physical" achievements like the use of drones and other autonomous tools. There are also concerns related to introduced vulnerability and cyber security, which become even more important than before.

Challenges and opportunities

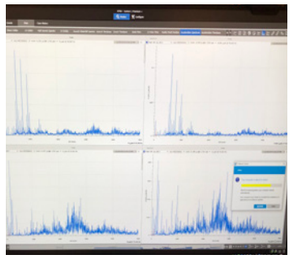
Predictive maintenance means that maintenance decisions are based on information regarding the current state of components and assets and future state development. There is a large variety of condition monitoring technologies available today to assess the current state. This is often referred to as diagnostics. For rotating equipment, signal processing of vibration measurements has been available for decades, similarly to ultrasonic measurement and magnetic particle inspection utilized for structure inspection. A challenge is still how to use these models and tools for prognostics, i.e., prediction of remaining useful lifetime required for maintenance planning.

For larger systems involved in the production and processing of hydrocarbons, there is no single sensor that can capture the state of the system. The idea is to use information for a set of sensors to monitor relevant process parameters like pressure, temperature and flow. Then surveillance systems are trained to recognize the normal situation, and then establish algorithms for efficient anomaly detection. The literature reports on successful implementation of both machine learning algorithms and algorithms based on the so-called first principles. However, to scale up such approaches for an entire installation seems challenging and we see the need for "self learning" approaches in order to implement anomaly detection on a large scale.

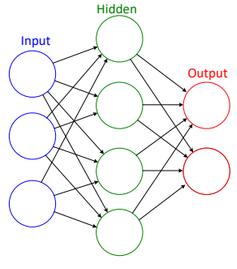
A digital twin is a digital representation of a real-world entity or system. The implementation of a digital twin is an encapsulated software object or model that mirrors for example a physical system, historical and future maintenance activities, or an operational plan. Data from multiple digital twins can be aggregated for a composite view. The notion of a digital representation of real-world entities or systems is not new. Its heritage goes back to computer-aided design representations of physical assets or profiles of individual customers. The difference in the latest iteration of digital twins (adopted from Gartner Top 10 Strategic Technology Trends for 2019) is:

(i) Robustness of the models with a focus on high reliability and efficient maintenance, (ii) digital twins' link to the real world, potentially in real-time for monitoring and control, (iii) application of advanced Big data analytics and AI/ML, and (iv) ability to interact with them and evaluate "what-if" scenarios.

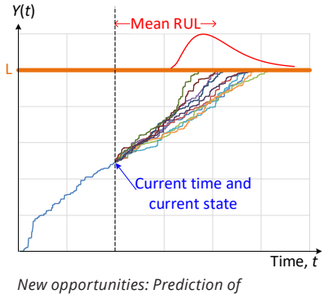
In the O&G industry we see a huge effort in implementing digital twins. Systems drawings, system documentation, available data and sensor information are connected to represent a digital twin of the system. However, these digital twins often suffer from lack of comprehensive mathematical system models which enable what-if scenario analyses required to optimize maintenance and operations decisions. This is an important topic for our research.



Existing technology: Vibration analysis (NTNU RAMS lab)



New digital technology: Artificial neural network



New opportunities: Prediction of remaining useful lifetime (RUL)

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Cyber safety and cyber security: There is no free lunch! This also applies in relation to the digitalization taking place these days. Cyber security and safety have to be dealt with in a systematic manner. Several malicious cyber-attacks have been reported in the literature. Examples are the Maroochy Water Breach event, the Stuxnet malicious computer worm causing substantial damage to Iran's nuclear program, and finally the Hydro aluminium security attack where costs after just one week were estimated to 30 million euro. In addition to malicious acts we also have cyber safety challenges like the Boeing MAX 737 catastrophe exemplifying how automated solutions might fail, and also the challenges related to integrating technology, people and organizations.

Research strategy

The research on operation, maintenance, safety & security will focus on developing digital tools, solutions and new ways of working for optimized and safe operation:

- Predictive maintenance
  - Anomaly detection, fault diagnosis and remaining useful lifetime prediction
  - Decision support models for planning and optimizing maintenance
- Safety and risk analysis
- Control and safety systems technologies
- ICT/Cyber-security analysis
- Requirements for, development of and demonstration on the use of digital twins

Current PhD projects

Maintenance optimization in remote operations
PhD candidate: Abu Md Ariful Islam, Main supervisor: Jørn Vatn, Sponsor: AkerBP

The project focuses on the optimization of the maintenance activities in the context of unmanned/minimum manned platforms in remote offshore operations, where physical maintenance opportunities are limited. The main objective of the research is to investigate and develop optimal maintenance strategies for critical assets to efficiently utilize such limited opportunities. The focus of the research is to utilize available condition monitoring data of selected assets to develop failure prediction models and maintenance decision models to support maintenance in remote operations.

Predictive maintenance
PhD candidate: Ewa Maria Laskowska, Main supervisor: Jørn Vatn, Sponsor: Lundin

Modelling of degradation of safety valves (ESVs). The methodology is based on stochastic processes such as the Markov process or Wiener process. The idea is to enable prediction of Remaining Useful Lifetime (RUL) distribution, given the current degradation level of valve is known. Next, the obtained RUL can be used for optimization of inspection regimes. Degradation models assuming constant inspection intervals have been developed. The aim is to extend the modelling framework to treat the situation where inspection intervals depend on the current condition and the predicted RUL. Outcome of the project: Stochastic degradation models enabling RUL prediction and real-time optimization models taking condition and operational constraints into account.

Industry 4.0 and smart predictive maintenance
PhD candidate: Tom Ivar Pedersen, Main supervisor: Per Schjølberg, Sponsor: NTNU

Recent developments in sensor technology combined with improvements in systems for collecting, storing and analyzing large amounts of data, often associated with the term Industry 4.0, are expected to bring substantial changes to how maintenance and asset management will be conducted in the upcoming years. One example of this is predictive maintenance which has the potential to reduce maintenance costs by allowing maintenance organizations to focus resources on the right equipment at the right time, and improve safety and availability by reducing the level of unplanned corrective maintenance. Outcome of the project: Methods and models that explore how digital solutions can be used to improve the economic value generated from a production asset.

Safety and security in design and operation of ICS systems
PhD candidate: Bálint Zoltán Téglásy, Main supervisor: Mary Ann Lundteigen, Sponsor: NTNU

New networking applications are now to be implemented in the oil and gas industry. These digital technologies provide unique opportunities and pose unique threats to critical infrastructures. The functional safety regulation stemming from the industrial sphere and the cyber security policies enforced in enterprise-grade information technologies will be interfacing through electronic communication. Clarifying the design, verification and operation procedures for future control systems will allow companies to retain sufficient control of their facilities while taking advantage of IoT and Industry 4.0 functionalities. Outcome of the project: Design philosophies and architectures that minimize the threats while retaining the opportunities of networked control systems. This will allow for long-term accident-free, economically viable and environment-friendly operation.

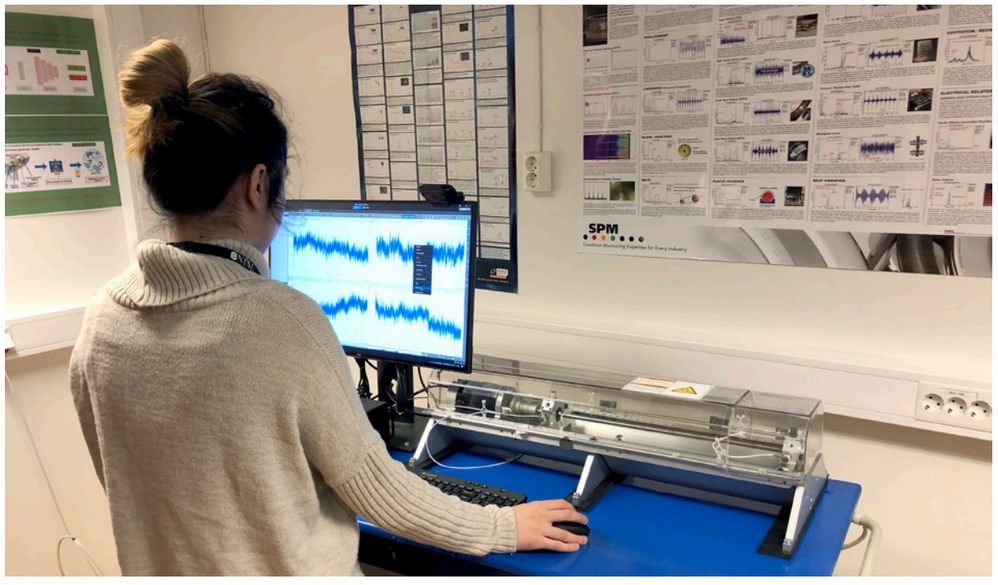
Projects to be started in 2020

Predictive maintenance and residual useful lifetime prediction
PhD candidate: to be hired, Main supervisor: Per Schjølberg, Sponsor: OKEA

The aim of predictive maintenance is to ensure that appropriate maintenance tasks are executed at optimal points in time. This requires a proper understanding of the technical health of the asset and in particular how the technical health will develop over time as a function of future operational loads. Expected outcome of the project: A set of Residual Useful Lifetime prediction models accompanied by prototype computer codes and case studies.

Risk based maintenance
PhD candidate: to be hired, Main supervisor: Per Schjølberg, Sponsor: Equinor

Risk based maintenance is emerging as a key method for obtaining world class maintenance planning and execution. It integrates a reliability approach and a risk assessment strategy to obtain an optimum maintenance schedule for an asset. This type of maintenance is linked to an operational concept that determines the most economical way to distribute resources, so that the maintenance effort is optimized to minimize the risk and consequences of failures. Expected outcome of the project: Artificial Intelligence/ smart algorithms and development and implementation of new digital technologies.



Laboratory equipment for experiments on predictive maintenance.

New business and operational models

Organizational and technological preconditions for the realization of the digitalization and Industry 4.0 potential

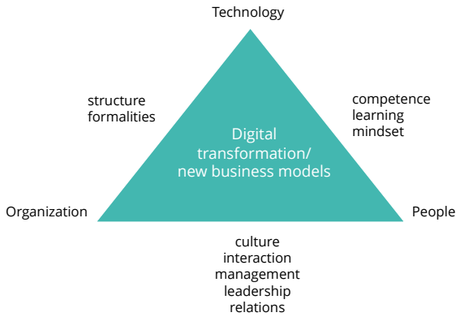
Three major trends are driving the digital transformations in the petroleum industry. The first is the development and implementation of new technologies throughout the O&G value chain, such as automation, remote operations, and use of artificial intelligence. The second trend concerns how the organizations operate, not only internally, but also how they relate to and cooperate with customers and suppliers. The third trend is pointing towards new products and business models.

Challenges and opportunities

New E&P-technologies are forces that affect organizational structures, work processes and culture, but may also represent new kinds of safety challenges. An example is remote operations of offshore installations, which require new communication and cooperation patterns, and that may also influence safety and security procedures.

Novel digital tools for cooperation, communication and coordination are opening new possibilities for improved collaboration throughout the value chains and for overcoming internal barriers and silos between departments and professions. Efficient ways of sharing information and experience and the organization's ability to exploit diverse competencies stand out as preconditions for innovation. Innovative development of new products and processes are often also dependent on coordinated efforts, involving partners, suppliers and customers.

Successful digital transformations, increased operational safety, and development of new business models are dependent on the alignment of technology, organization and people. (In the safety domain this corresponds to the well-known MTO approach – "mennesker, teknologi og organisasjon.) This is illustrated in the figure below. The figure also indicates variables that describe central organizational characteristics and how people relate to technology.



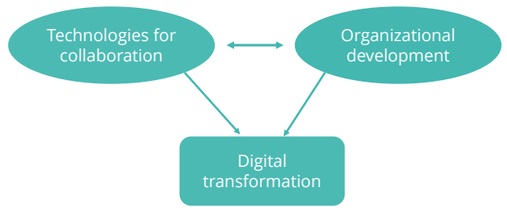
Research strategy

One of the basic questions addressed in this program area is then: What are the organizational and technological preconditions for succeeding with digital transformation and the application of new business and operational models, and how can such change processes be managed?

The terms cooperation and collaboration are often used interchangeably, but it is probably more accurate to say that collaboration is a specific form of cooperation, where the participants also have a shared or common goal. To work towards a common goal therefore presupposes alignment of interests. Such collaboration is a key, and in many cases a necessity, for improved performance. A relevant example is new forms of collaboration across different fields of expertise, business units and companies through digital tools, e.g. digital software platforms for field development. Another possibility is new ways of enhancing team performance through monitoring and suggestions for optimization through digital tools that can give inputs for improved decision processes.

Well-functioning organizations sometimes succeed in developing collaborative communities, which are formed when people work together to create shared value. Collaborative communities rest on a common cultural foundation, sharing "a distinctive set of values, which we call an ethic of contribution". Developing these kinds of organizational qualities is especially important in knowledge-intensive industries that are dependent on continually mobilizing talents and expertise in flexible group-work efforts. Digital technologies can be important tools in the build-up and maintenance of collaborative communities.

The main challenge for organizations which strive to overcome siloization and obtain collaboration is not to develop new digital tools, but find efficient ways of utilizing tools that are already available on the market. In other words: this is a question of enabling technologies and



Program area team

Program area manager
Per Morten Schiefloe
Prof. Sociology

Program area co-manager
Eric Monteiro
Prof. Information Systems

Mary Ann Lundteigen
Prof. Safety of Automation Systems

Kenneth Duffaut
Assoc. Prof. Geophysics

Vidar Hepsø
Adj. Prof. Digitalization, Equinor

Itishree Mohallick
PhD candidate

Nataliia Korotkova
PhD candidate

Erlend Fjøsna
TechnipFMC

organizational development. We can also say that this is a necessary step towards "Industry 4.0" – realizing the long-term effects of digital technologies – transformation, not only substitution. Relevant research questions following from this are, among others:

- Distributed organizations and remote operations – cooperation, coordination and safety
- Safe and secure digital work processes
- Organizational development for digital transformations

Current phd projects

Digital Relations and New Business Models
PhD candidate: Nataliia Korotkova, Main supervisor: Per Morten Schiefloe, Sponsor: TechnipFMC

Digital technologies have significantly altered the connectivity and flexibility in the business ecosystem. Improved collaboration and early customer engagement in the value chain open new possibilities for network-based business models, increased efficiency and reduced costs. The main research questions in this PhD project are: (1) What new ways of collaboration in the complex value chain are made possible in the digital age? (2) What can facilitate or constrain the inter- and intra-organizational collaboration in the oil and gas value chain? (3) How can digital technologies assist in overcoming organizational silos? (4) What is the role of human-to-human and human-to-machine trust for digital transformation?

Collaboration and digital tools in early stage design of offshore facilities
Phd Candidate: Itishree Mohallick, Main supervisor: Eric Monteiro, Sponsor: TechnipFMC

The empirical case in this project is a global leader on onshore/offshore, subsea and surface technologies for the petroleum industry. As an EPC (Engineering, Procurement and Construction) provider, the organization works with the concept development, feasibility studies and FEED (Front End Engineering and Design), as well as the production and installation of offshore infrastructures, such as pipelines and production facilities – EPC projects. The series of business operations from concept until delivery are in focus in this PhD project. The objective is to study the pattern of collaboration between the EPC provider and their customers (oil companies) and the exploitation of digital tools, in the parts of the value chain reaching from concept development to FEED.

Projects to be started in 2020

From idea to discovery: information sharing and cooperation in the exploration value chain
PhD candidate: to be hired, Main supervisor: Per Morten Schiefloe, Sponsor: Neptune Energy

This project focuses on workflow, collaboration, use of digital tools and decision-making in the early phases of the exploration value chain. Important questions to be studied are: (1) participants, roles, dependencies and interfaces, (2) drivers and barriers for collaboration, impacts of organizational contexts and surroundings, (3) networks, relations and trust between the companies involved, (4) data sharing, barriers for data sharing, strategies for improved data sharing, digital technologies for improving the work processes and risks associated with such technologies, (5) new business models and preconditions for innovation in the value chain.

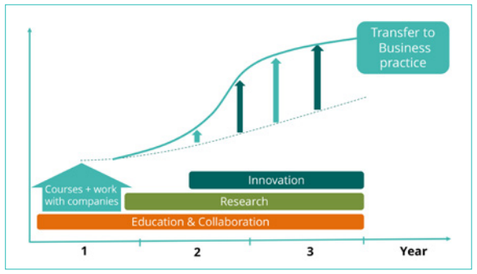
Remote operations and future operating models
PhD candidate: to be hired, Main supervisor: Mary Ann Lundteigen, Sponsor: Equinor

Remote functions, such as remote control or remote monitoring, have been used for a long period for oil and gas production facilities, especially to control and monitor remote unmanned satellite platforms. More recently, we see increasing use of more advanced remote functions (e.g., remote operations, engineering and risk-based maintenance) over longer distances from production sites. Remote operation is more than remote control, the operational model/concept is the key. This project will focus on identifying and analyzing the technical and organizational capabilities that need to be in place to succeed with this transformation. Relevant use cases will be identified and utilized actively as basis for the research. The project aims to strengthen the fact base for remote operation and future operating models.

BRU21 Ecosystem

Education, Collaboration, Research, Innovation

BRU21 projects follow the S-curve presented in the figure below. Research activities are boosted by common Education, Collaboration, Research and Innovation activities organized within the program.



Education

In the beginning of the project, PhD candidates focus on taking relevant courses, learning the use-case and obtaining industrial data. As part of this work, in 2018-2019 there were over 70 meetings with the companies, once every quarter per project, on average. These meetings resulted in the transfer of relevant expertise and data from companies to the research projects, establishing a firm foundation for subsequent research.

PhD course program

Each PhD candidate must take a program of 30 ECTS points (about 4 courses) as part of the formal requirements for obtaining a PhD degree. By the end of 2019, BRU21 PhD candidates successfully completed 72 courses, which constitutes 93% of all obligatory courses to be taken by the PhD candidates. The remaining courses will be taken according to project research plans and course schedules.

To ensure delivery of relevant courses to PhD candidates, BRU21 program organized two invited PhD courses:

- Decision analysis, by Prof. Reidar B. Bratvold (University of Stavanger)
- Mixed integer optimization methods with application to production optimization, by Prof. Eduardo Camponogara (Federal University of Santa Catarina, Brazil).

BRU21 forum

To provide the continuous education for BRU21 team members, the program organized the BRU21 forum. It is a platform for knowledge exchange on state-of-the-art research, innovation and industrial developments in digital and automation technologies for the oil and gas industry. With contributions from leading academic and industrial experts in the field, the BRU21 forum is open to all participants from NTNU and to BRU21 partner companies.

MSc students

Involvement of MSc students in BRU21 is an important part of the program's education activities that both support PhD projects and educate multidisciplinary (digital/petroleum) specialists for the industry. In 2018-2019, there were 45 students working on topics of BRU21 research and supervised by BRU21 team members. This includes NTNU's Drillbotics team. Drillbotics is an international student competition on autonomous drilling organized by the Society of Petroleum Engineers. In 2019, the NTNU team was placed #1 in intermediate ranking. In 2018, the NTNU team took the first place in the finals among 9 teams from universities in the USA, Norway, Canada and Germany.

NTNU Drillbotics team 2019 at the finals at Clausthal University of Technology, Germany

Collaboration

New ideas are often born "next to a coffee machine". Communication and collaboration among the team members, both on work and social levels is an important factor of success for research and innovation.

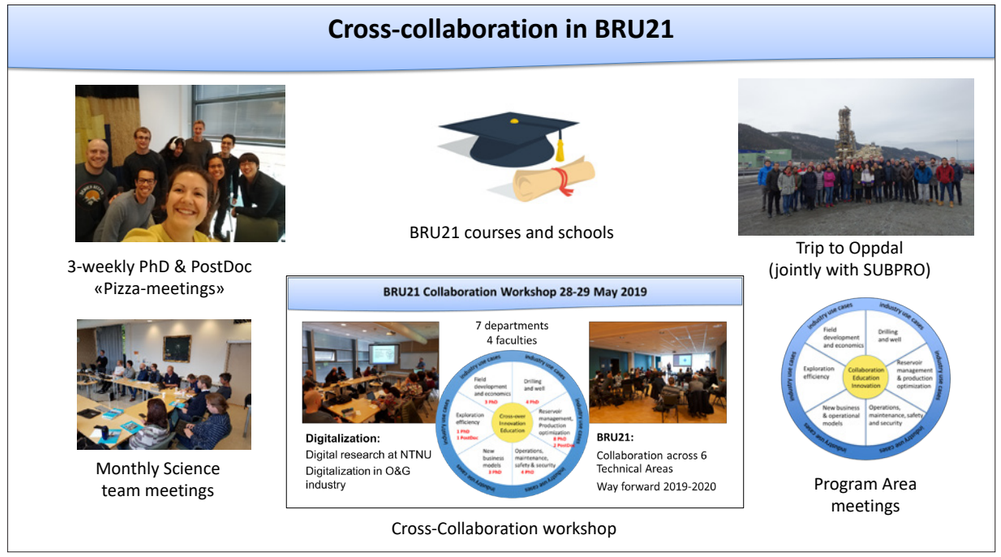
Cross-collaboration statistics

According to a survey on BRU21 cross-collaboration during 2019, 18 PhD candidates and postdocs contributed to other BRU21 projects and 15 acknowledged that they received valuable inputs from other BRU21 projects. This corresponds to 95% involvement in cross-collaboration among the 19 PhD candidates and PostDocs employed in BRU21 longer than 4 months. 13 and 11 respondents indicated that they got valuable inputs from BRU21 professors other than their own supervisors and from NTNU professors outside of BRU21, respectively.

Meetings and workshops

The cross-collaboration culture in BRU21 is established through various activities that focus on avoiding silos:

- Program area meetings were organized to establish and/or enhance collaboration and exchange of ideas within each of the six BRU21 program areas.
- BRU21 Science team (monthly) meetings were held to discuss further directions for research and program development.
- BRU21 collaboration workshop held in May 2019 was organized to enhance collaboration across BRU21 program areas, as well as with other units at NTNU.



Social activities

- To enhance informal contacts between PhD candidates and PostDocs, BRU21 organized regular (every 3rd week) "Pizza meetings" – informal lunch and learn meetings with "no professors allowed".
- SUBPRO-BRU21 common trip on 22-23 March 2019 brought together teams from both the BRU21 program and the SFI center SUBPRO[1] to enhance their social interaction and research collaboration. BRU21 and SUBPRO have many synergies to be exploited.

External collaboration

INTPART project: NTNU Departments of Engineering Cybernetics and Geoscience and Petroleum, with support of BRU21, were granted a 3-year funding for phase II of INTPART collaboration project "Production optimization", between NTNU and Federal University of Santa Catarina (UFSC), Brazil. As part of the project, VIIIth Oil and Gas Production Optimization Workshop was organized on 29-30 April, 2019 in Petrobras Research Center – CENPES, Rio de Janeiro. In addition to the workshop, the INTPART project also sponsors the exchange of students and professors between UFSC and the NTNU/BRU21.

Machine learning and Artificial Intelligence: BRU21 and SUBPRO initiated research collaboration on the topics of Artificial Intelligence (AI) and Machine Learning (ML) for petroleum industry. Similar agreement on intentions was reached with the management of Norwegian Open Artificial Intelligence Laboratory. To further strengthen its position within AI/ML, BRU21 hired an adjunct professor Ivan Tyukin (20% FTE) from Leicester University, UK. This will also enable BRU21 collaboration with the AI/ML environment in that university.

External experts: On the project level, the program involves NTNU professors from outside BRU21, when their expertise is needed to solve the use-case challenge.

Research

Publications: In 2019, 23 papers and conference presentations were published/given by BRU21 team members. By the end of 2019, 22 publications were in preparation by BRU21 PhD candidates and PostDocs.

Digital update project: To define BRU21 scientific identity and directions for further research, the program initiated the BRU21 Digital Update project – a systematic review of industrial challenges and opportunities provided by digital/automation technologies to formulate the vision of digitalization research in each BRU21 program area. Results of the project are to be published in 2020.

Innovation

Main innovation activities in BRU21 are to be started in 2020. In 2018-2019, BRU21 team members were offered innovation courses from NTNU Ocean School of Innovation (OSI). According to OSI statistics, BRU21 PhD candidates and PostDocs were the second-largest group of participants at OSI courses in 2019. In 2019, BRU21 initiated a workflow for IP protection of research results. This was done based on a pilot idea submitted to the NTNU Technology Transfer Office (TTO) for patenting.

Associate Professor Sigve Hovda, a member of BRU21 science team, received 1MNOK from NTNU Discovery Fund for his project Dynamic drill string model for oil and gas drilling.

[1] SFI center SUBPRO – Center for Research-based Innovation within subsea production and processing (www.ntnu.edu/subpro)

Interviews with BRU21 team members

Milan Stanko, Associate Professor in Petroleum Engineering, leads the BRU21 Program area "Field development and economics" He underlines the importance of cooperation with the industry.

"Our industry partners are open to cooperate and our students and fellows are eager to make a difference."

I believe BRU21 has the potential to create significant value for the industry and society and promote a step change in current working processes. The program was designed after a thorough fact-finding process and most projects are based on use cases and challenges from industrial partners. Moreover, we have a multidisciplinary and highly competent team working in close communication with the industry. Therefore, I believe the chances of success and generating value are high. Potential outcomes are mapping the applicability of digital solutions in the oil and gas industry, creating new solutions and proposing roadmaps for implementation.

Can you tell us about your role in the BRU21 project?
I lead the Program area "Field Development and Economics" that currently has a total of four exciting projects from which I supervise two. To tackle the research tasks in our area we need to combine several types of expertise, consider the human factor and unforeseen events and often reach compromises between pragmatism and rigorousness. My field of expertise is petroleum production, which is also extremely multidisciplinary.

How is your experience working with the industry and other partners in this project?
The contact and cooperation with the industry in BRU21 has been interesting, motivating and fun. Our industry partners are open to cooperate and our students and fellows are eager to make a difference. This keeps motivation high in the project, it allows one to make adjustments along the way and hopefully increases understanding and chances for early adoption.

What is special about this program?
BRU21 was created by analyzing in depth current trends, gaps and needs and is built over specific proposals and use cases in mind. This allowed us to secure funding solely from industrial partners and internal funds, which is quite remarkable compared to other research programs in the area, especially considering the size of BRU21.

This is a multidisciplinary project. Tell us what it is like to work this way - what is the benefit?
To work in a multidisciplinary project is interesting, eye-opening and humbling. In my opinion multidisciplinary work allows one to see the big picture, promotes technical growth by working outside of our comfort zone and opens the opportunities to borrow and implement solutions from other fields.

Mary-Ann Lundteigen, Professor in Safety of Automation Systems, is a co-manager of the Program area "Operations, maintenance, safety and security". She believes the BRU21 program can be of great benefit to the industry and society in general.

"Being multi-disciplinary stimulates the development of new types of collaborations and new types of projects."

-The oil and gas industry is an important industry for society by generating large value and technological developments and it is therefore important that we can contribute with relevant competence and new knowledge that can support this industry's ability to operate safely, with a low carbon footprint and high cost efficiency.

It is not easy to attract students to this sector, as there has been many "ups and downs" in the last few years and forecasts that the industry is soon to close down. What may not be so well communicated, is that the industry will be of great importance for Norway for many years to come. This does not mean that the industry will remain as it has been in the past, but will develop and renew itself to accommodate new technology opportunities and societal requirements.

For example, the industry is developing and qualifying new technologies to accommodate new ways of operating, for example by remote operation of unmanned facilities, to reduce the need to transport people as often to and from platforms. This necessitates various use of robotized inspections and simple maintenance. The industry is also developing and deploying solutions to share data securely and efficiently from platforms and into advanced applications for risk monitoring, condition monitoring and prognostics, and plant-wide optimization. More focus is

now placed on reducing the climate footprint of oil and gas exploration and production, which may call for new systems to be introduced as well as the re-thinking of established concepts.

BRU21 can play an important role in this respect as an arena and engine of initiating PhD and master's projects and thus attract young people to this industry.

Can you tell us about your role in the BRU21 project?
My role is co-managing the BRU21 Program area "Operations, maintenance, safety and security". I am currently supervising one PhD student in the area of cyber security industrial control and safety systems (funded by NTNU) and will soon start a new PhD project (funded by Equinor) on remote operations. My personal interest is the design and operation of safety-instrumented systems, with focus on safety as well as security.

What is your experience working with industry and other partners in this program?
My main collaboration has involved some interaction with Gassco, and more extensively with Equinor, where both of my activities will be linked to Equinor case studies. However, I also have an extensive collaboration with the industry outside BRU21 that may be useful, including the PDS forum (a forum gathering key actors from oil companies, engineering, manufacturers, consultancy, research institutes (SINTEF/NTNU) and authorities involved in design and operation of safety-instrumented systems in the oil and gas industry, the CDS forum (a similar forum as PDS, but with focus on cyber security I am also a co-director of SUBPRO, the 8-year research-based innovation center that started in 2015.

What is special about this program?
I think BRU21 is unique in the way that it is quite an open and cross-disciplinary center, with a firm basis in the priorities from the BRU21 report (NTNU strategy for oil and gas research and education). I think the model around the PhD project with two supervisors and industry mentor/contact point is very good. This network is also vital for initiating relevant topics for master's projects. The social environment where people involved gather, sometimes also in collaboration with SUBPRO, is also unique and very important.

This is a multidisciplinary project. What is it like to work this way - what is the benefit?
Being multi-disciplinary stimulates the development of new types of collaborations and new types of projects. It also gives the opportunity to create a platform to link new initiatives and ongoing projects around the same or similar study cases – approached from different perspectives. My impression is that the new generation of PhD candidates is used to working in teams, and being part of an environment that is larger than his/her own project may be a premise for whether or not the students will be satisfied.

PostDoc Thiago Lima Silva is working on data-driven production optimization. He highlights the multidisciplinarity of the projects, multinationality of the team, and close relationship between academia and the industry as major benefits of the BRU21 program.

"As an NTNU funded Postdoc, I work on fundamental research, and also contribute to research on industrial use-cases in other BRU21 projects."

My BRU21 project is on Data-Driven Production Optimization. The project falls into the reservoir management and production optimization program area, where the focus lies on overarching goals that maximize the return value of the investments in terms of recovery of hydrocarbon reserves. More specifically, the project involves the investigation of novel methodologies that incorporate real-time data into optimization schemes with the aim to improve the performance and robustness of the solutions.

In the long-term, the main challenges are determining the well trajectories and well controls that maximize the field profit for its entire production time under geological uncertainty. On a shorter time-scale, the challenge consists in performing automatic production optimization of artificially lifted fields when the production parameters of the wells are uncertain.

What is your background?
I hold a bachelor's degree in computer science from the Federal University of Bahia, Brazil, and an MSc degree and a PhD degree in Systems and Automation Engineering from the Federal University of Santa Catarina, Brazil. My PhD focused on the development of optimization

methodologies to support decision making in daily operating workflows. During the PhD, for a period of 3 years, I worked on a part-time contract with the Research Centre of Petrobras in a project for the production optimization of Petrobras' assets in the Santos Basin, which is located offshore from the southeast coast of Brazil. In the 4th year of my PhD, I did an internship for 1 year at the Department of Engineering Cybernetics, NTNU where I worked in a project that involved coupling gathering network and reservoir models in order to ensure feasibility of optimized well controls in long-term plans.

Can you tell about your current collaboration with industry and with other BRU21 projects?
As an NTNU funded Postdoc, I work on fundamental research, and also contribute to research on industrial use-cases in other BRU21 projects. More specifically, I am currently collaborating with 3 PhD projects involving production optimization. The first is Joakim Andersen's project, which involves the development of a novel methodology to reconciliate long-term and short-term goals in the optimization of oil production systems. The second is Brage Kristoffersen's project (sponsored by Equinor), which consists of a novel method for robust well placement optimization with the use of an automatic well planning techniques based on neural networks. The third is Seok Ki Moon's project (sponsored by AkerBP), which involves the exploration of automated methodologies and development of decision-support tools that allow including environmental constraints and energy efficiency in the field planning phase. Further, I am also involved in two external collaborations: an INTPART project with the Federal University of Santa Catarina in Brazil, and a project with the Schlumberger Research Centre in Stavanger. The first involves the development of derivative-free methods for well control and well placement optimization, while the second involves the design optimization of inflow control devices while drilling.

What is your experience working in the BRU21 program?
I really enjoy working in BRU21 for several reasons: multidisciplinarity of the projects, multinationality of the team, and close relation between academia and the industry. In my opinion, these elements combined make the environment extremely rich for one's professional development. Further, I feel particularly pleased to be able to use my background to support other projects, while also learning different perspectives on common challenges.

PhD Candidate Mathilde Hotvedt works with machine learning for more efficient oil production, and likes the BRU21 program's connection to the industry.

"The knowledge that my work may be utilized for something real is a large motivation in my everyday work."

I am working on hybrid modelling in the oil and gas industry. The main goal is to combine already existing simulators with artificial intelligence such that all available knowledge about the system, for instance physical laws, prior knowledge and process data, may be utilized to its full extent. Hopefully, the combination will enhance the predictive performance and give more insight about the process, and possibly lessen the computational demand of the simulators such that they may be more suitable for real-time optimization. Currently I am working with choke modelling – but the approach may be utilized for all components in the petroleum production system.

What is your background?
I took my master's degree at the Department of Engineering Cybernetics, finishing spring 2018. I started straight away on the PhD – so no experience with the industry. However, I did write my master's thesis in cooperation with a company called "Cybernetica AS" where modelling and control of a CO2 capture facility was the topic of the thesis. In that way, I do have some experience with the industry.

Can you tell about your current collaboration within BRU21?
My sponsor is Lundin Norway and I am very satisfied with their interest and helpfulness so far. Through Lundin, I am currently collaborating with another company called Solution Seeker. Their work is closely related to mine and I find it ideal to work closely with them. I am also co-supervising two MSc students on topics closely related to my project.

What is your experience working in the BRU21 program?
I like the way the BRU21 project is organized where the goal is to connect (almost) all projects to the industry. This gives us a head start into the industry for those who want to head in that direction after the PhD, and gives us major advantages when it comes to data collection and real-life issues. The knowledge that my work may be utilized for something real is a large motivation in my everyday work.

Publications

Journal

1. Schulze, F. S., Dalle A.G; Imsland, L.S., Harjunkoski, I. 2019. "Optimal Maintenance Scheduling for Washing of Compressors to Increase Operational Efficiency". Computer-aided chemical engineering, Volume 46. pp. 1321-1326.
2. Andersson, L. E., Scibilia, F., Imsland, L.S. 2019. "An iceberg forecast approach based on a statistical ocean current model". Cold Regions Science and Technology, Volume 158. pp. 128-142.
3. Monteiro,E., Parmiggiani, E. 2019. "Synthetic Knowing: The Politics of the Internet of Things". MIS Quarterly Volume 43(1), pp. 167-184.
4. Parmiggiani, E., Monteiro, E. "Digitized Coral Reefs". DigitalSTS: A Field Guide for Science & Technology Studies. Princeton University Press 2019 ISBN 978-0-691-18707-5. pp. 300-325.
5. Silva, T.L., Codas, A., Stanko, M., Camponogara, E., Foss, B.A. 2019. "Network-Constrained Production Optimization by Means of Multiple Shooting". SPE Reservoir Evaluation and Engineering 2019, Volume 22(02), pp. 709-733.
6. Hovda, S. 2019. "Multi-dimensional semi-analytical model for axial stick-slip of a rod sliding on a surface with Coulomb friction". Advances in Mechanical Engineering 2019, Volume 11(3), pp. 1-12.
7. Hovda, S. 2019. "Optimal procedures for lowering and applying weight on the bit when starting to drill." Journal of Petroleum Science and Engineering 2019, pp. 872-879.

Conference papers

1. Arnø, M. L., Thuve, A., Knoop, S., Hovda, S., Pavlov, A., Florence, F. 2019. "Design and Implementation of a Miniature Autonomous Drilling Rig for Drillbotics 2018". SPE/IADC Drilling Conference and Exhibition. The Hague, The Netherlands.
2. Egeland, R. L., Lescoeur, A., Olsen, M. A., Vasantharajan, M., Hovda, S., Pavlov, A. 2019. "Miniature Robotic Drilling Rig for Research and Education in Drilling Automation". IEEE Conference on Control Technology and Applications (CCTA). IEEE conference proceedings 2018 ISBN 978-1-5386-7698-1, pp. 736-741.
3. Pedersen, T. I., Schjølberg, P. 2019. "The Economic Dimension of Implementing Industry 4.0 in Maintenance and Asset Management". 9th International Workshop of Advanced Manufacturing and Automation, IWAMA 2019; Plymouth; United Kingdom. Volume 634 LNEE, 2020, pp. 299-306.
4. Hotvedt, M., Hauger, S. O., Gjertsen, F., Imsland, L.S. 2019. "Dynamic Real-Time Optimisation of a CO2 Capture Facility". 12th IFAC Symposium on Dynamics and Control of Process Systems (DYCOPS 2019), Florianapolis, Brazil.
5. Islam, A. Md A., Srivastav, H., Vatn, J., Barros, A., Lundteigen, M.A. 2019. "Time-dependent Unavailability Assessment of Final Element of Safety Instrumented Systems- an Application of Multiphase Markov Process". Proceedings of the 29th European Safety and Reliability Conference (ESREL)., Hannover, Germany.
6. Laskowska, E., Vatn, J. 2019. "State Modelling and Prognostics of Safety Valves used in the Oil and Gas Industry". Proceedings of the 29th European Safety and Reliability Conference (ESREL). 22 – 26 September 2019, Hannover, Germany, pp. 1285-1292.

Conference presentations

1. Arnø, M. L., Thuve, A., Knoop, S., Handeland, A.S., Turøy, P.Ø., Hovda, S., Pavlov, A. 2019. "Design and implementation of a miniature autonomous drilling rig". VIII Oil and Gas Production Optimization Workshop, 29-30 April 2019, Rio de Janeiro, Brazil
2. Nystad, A.N., Pavlov, A., Schiefloe, P.M., Monteiro, E. 2019. "People Development for Digitalization in Oil and Gas Industry: BRU21 perspective". VIII Oil and Gas Production Optimization Workshop, 29-30 April 2019, Rio de Janeiro, Brazil
3. Pavlov, A. 2019. "BRU21: NTNU Research and Innovation Program in Digital and Automation Solutions for Oil and Gas Industry", CIUS Conference, 2-3 May, 2019, Oslo, Norway
4. Pavlov, A. 2019. "The BRU21 vision of autonomous operations", SINTEF Petroleum Conference; 19-20 March 2019, Trondheim, Norway
5. Monteiro, E. 2019. "Digital oil". Distinguished scholar lecture, Warwich Business School, March 2019
6. Silva, T.L., Bellout, M., Giuliani, C. M., Camponogara, E. 2019. "Derivative-free algorithms and applications for production optimization". VIII Oil and Gas Production Optimization Workshop; 2019-04-29 - 2019-04-30
7. Bellout, M., Baumann, E., Kristoffersen, B.S., Silva, T.L. 2019. VII Oil and Gas Production Optimization Workshop, 29-30 April 2019, Rio de Janeiro, Brazil
8. Korotkova, N., Mohallick, I., Schiefloe, P.M. 2019. OASIS, the IFIP Working Group 8.2 Research Workshop. 14 December 2019, Munich, Germany
9. Korotkova, N., Horn, M. 2019. "Betydningen av tillit 4.0 og kommunikasjon 4.0 i tidsalderen for digitale organisasjoner". NEON-konferansen, 26-28 November 2019, Lillehammer, Norway
10. Korotkova, N., Horn, M. 2019. "What does the concept of trust mean in the age of digital organizations?". Production of Participation in the Digital World Workshop, 12-13 December 2019, Trondheim, Norway

BRU21 Annual Report 2019

People in BRU21 program

Program management

Egil Tjåland
Program owner, Head of Department of Geoscience and Petroleum

Professor Alexey Pavlov
Program manager, Professor in Petroleum Cybernetics

Arild Nystad
Coordinator Industrial relations

BRU21 Program area managers

Kenneth Duffaut
Associate Professor Geophysics and Rock Physics, manager of PA1

Milan Stanko
Associate Professor Petroleum Engineering, manager of PA2

Sigbjørn Sangesland
Professor Petroleum Engineering, manager of PA3

Lars Struen Imsland
Professor Optimization and Control, manager of PA4

Jørn Vatn
Professor Maintenance, Risk & Optimization, manager of PA5

Per Morten Schiefloe
Professor Sociology, manager of PA6

BRU21 Science team

Verena Hagspiel
Professor Investment and Finance, co-manager of PA2

Asgeir Tomasgard
Professor Industrial Economics and Technology Management

Sigve Hovda
Associate Professor Drilling Engineering

Behzad Elahifar
Associate Professor Drilling Engineering

Carl Fredrik Berg
Associate Professor Reservoir Engineering, co-manager of PA4

Morten Hovd
Professor Optimization-based Control

Ashkan Jahanbani Ghahfarokhi
Associate Professor Reservoir Engineering

Per Schjølberg
Professor Maintenance Management and Industry 4.0

Mary Ann Lundteigen
Professor Safety of Automation Systems, co-manager of PA5

Eric Monteiro
Professor of Information Systems, co-manager of PA6

Bernt Sigve Aadnøy
Adjunct Professor Drilling Engineering

Damiano Varagnolo
Professor Statistical Learning and Control

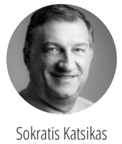
Frank Ove Westad
Adjunct Professor Big Data Cybernetics

Ivan Yurievich Tyukin
Adjunct Professor Artificial Intelligence and Machine Learning

Jon Kleppe
Professor Reservoir Engineering

Maria Lavrutich
Associate Professor Industrial Economics

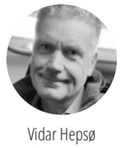
Mathias Bellout
Researcher Reservoir Engineering and Optimization



Sokratis Katsikas
Professor Cyber Security

Stephen Wolthusen
Professor Cyber Security

Tor Berge Gjersvik
Professor Subsea Engineering



Vidar Hepsø
Adjunct Professor Digitalization

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Ammar Ghanim

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Semyon Fedorov

Seok Ki Moon

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Abu Md Ariful Islam

Ewa Maria Laskowska

Tom Ivar Pedersen

Brage Strand Kristoffersen

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Postdoctoral fellows

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