

University of Oslo, Department of Informatics [Impact case #2]

Institution: University of Oslo
Administrative unit: Department of Informatics (IFI)
Title of case study: Knowledge-Driven Transformation of Engineering and Operations in Capital-Intensive Energy Facilities
Period when the underpinning research was undertaken: 2016-2022
Period when staff involved in the underpinning research were employed by the submitting institution: 2016-ongoing
Period when the impact occurred: 2019-ongoing

1. Summary of the impact

The KONKRAFT assessment of competitiveness of the Norwegian Energy Sector [1] identified manual and document-based processes as being driver of costs and a barrier to digital transformation and future competitiveness. These inefficient processes increase cost, in some areas by 20%, and reduce the performance of the built facility. Knowledge representation, or *Semantic asset modelling*, provides a theoretical and practical basis for moving from existing, document-based processes to data-oriented processes. The SIRIUS Centre for Research-Driven Innovation has provided methods and tools that have enabled a productive series of joint industry and collaborative projects in the oil & gas sector demonstrating how engineering and operational business processes in EPC companies (Aker Solutions, Aibel, TechnipFMC), operating companies (Equinor, AkerBP), and equipment vendors (Siemens, Bosch, Grundfos) can be transformed. The results have gained international attention. They have been anchored through open-source software, a DNV Recommended Practice, a new standard in the DEXPI organization for process design, contributions to IOGP practices, and a new ISO standard on Ontology Based Interoperability.

2. Underpinning research

Fundamental ICT research	Translational research	Application and demonstration
- Reasonable ontology templates (OTTR). - IDO – a foundational ontology for engineering data. - High-performance graph databases and query tools.	- Reference architecture and best practice for digital twins. - Information Modelling Framework (IMF) - Semantic representation of requirements. - Semantic management of identifiers in engineering data.	- READI joint industry project: Reference Designation System for Oil & Gas and IMF concept. - Digital Design Basis JIP. - DISC JIP: DEXPI standardization, integration of IMF with Industrie 4.0 standards, and implementation of IMF in industry.

The research focuses on the design of engineering-specific knowledge representation languages and associated methods. The languages and methods exploit, in a coherent framework, opportunities that

come from semantic web technologies to create interoperable knowledge graphs that can be queried, and logic-based languages that provide a precise declarative semantics. Together, they enable the use of automated reasoning to check the integrity and correctness of information.

The research has built on the translational ideas developed in the Optique EU project, where ontology-based data access was demonstrated in use for subsurface and operations data. Our work here can be classified into three categories. We build on a foundation of fundamental results with a set of translational methods. These then support application and demonstration within the engineering domain.

Reasonable Ontology Templates (OTTR) (<https://www.ottr.xyz>) is a language developed by SIRIUS researchers that simplifies the development and maintenance of knowledge models by engineers who are not experts in semantic technology [2], [3].

The **Industrial Data Ontology** is a vocabulary of relevant entities of the domain of interest with relationships that helps users build consistent models, build hierarchies of reference data, avoid categorical mistakes, and maintain data quality through the assistance of a tool that uses formal logic to check model integrity. IDO is under standardisation as a New Work Item in ISO Technical Committee 184 Sub-Committee 4 Industrial Data.

Implementation of these methods depends on access to **high-performance graph databases and query tools**, as developed in the Optique project [4]. We have worked further with the University of Oxford and Free University of Bolzano and their start-up companies, Oxford Semantic Technologies and Ontopic, to advance their methods and the RDFox and ONTOP software tools.

Translation to industrial application is done using **digital twins** as an implementation pattern. We have developed a simple but effective conceptual model of twins that aims to develop a best practice for digital twins for oil & gas [5], [6].

The **Information Modelling Framework language (IMF)** [7], [8] is a language that allows the construction of well-structured information models of engineered systems. It provides a way of moving from document-based engineering to data-based engineering in a way that is relevant to engineering practitioners. IMF makes use of the OTTR and IDO languages. The key feature of IMF is the capability to express and separate four different chains through a body of technical information: requirement/solution, abstraction, topology connectivity, and type/class hierarchies. IMF also supports different modalities that can be used to capture the different contexts that arise through the project lifecycle. IMF provides a bridge between knowledge representation technologies and systems engineering approaches.

This work was supplemented by work that provided simple semantic **representation of requirements** [9] and the selection and mapping of **identifiers** in engineering information systems [10].

The **application and demonstration** work took these methods and generated industrial results in collaboration with partner companies. The RDS for Oil & Gas [11], Digital Design Basis JIP [12] and DISC project with DEXPI participation [13] are described in the impact section below.

The SIRIUS team involved Dr. Martin Skjæveland (UiO), Dr. Baifan Zhou (UiO), Prof. Arild Waaler (UiO), Dr. David Cameron (UiO), Dr Dag Hovland (UiO, then Bouvet), Dr. Johan W. Kluwer (DNV), Dr. Foivos Psaromattis (UiO), Prof. Dimitris Kiritsis (UiO), Dr Evgeny Kharmalov (Bosch and UiO), Prof. Ian Horrocks (Oxford), Prof. Boris Motik (Oxford) and participants from SIRIUS partners Equinor, Bosch, DNV, Computas, Bouvet, and Aibel. We have collaborated with Aker BP, Aker Solutions, TechnipFMC, ConocoPhillips, Petrobras, Siemens AG, Siemens Energy, Grundfos, Standards Norway, NTNU,

University of Western Australia, Federal University of Rio Grande do Sul and Federal University of Espirito Santo.

3. References to the research

We have combined the research and impact references into a single list.

- [1] KonKraft, 'Project Competitiveness – changing tide on the Norwegian continental shelf - Summary and recommendations from the Committee', KonKraft, Oslo, Jan. 2018. Accessed: Dec. 12, 2021. [Online]. Available: https://konkraft.no/wp-content/uploads/2020/03/Summary_and_recommendations.pdf
- [2] M. G. Skjæveland, M. G. Veland, D. P. Lupp, L. H. Karlsen, and J. W. Klüwer, 'Chapter 22. OTTR: Formal Templates for Pattern-Based Ontology Engineering', in *Advances in Pattern-Based Ontology Engineering*, vol. 51, in *Studies on the Semantic Web*, vol. 51, IOS Press, 2021, pp. 349–377. doi: 10.3233/SSW210025.
- [2] D. P. Lupp, M. Hodkiewicz, and M. G. Skjæveland, 'Template Libraries for Industrial Asset Maintenance: A Methodology for Scalable and Maintainable Ontologies', in *CEUR Workshop Proceedings*, Volume 2757.
- [4] M. Giese et al., 'Optique: Zooming in on Big Data', *Computer*, vol. 48, no. 3, pp. 60–67, Mar. 2015, doi: 10.1109/MC.2015.82.
- [5] D. B. Cameron, A. Waaler, and T. M. Komulainen, 'Oil and Gas digital twins after twenty years. How can they be made sustainable, maintainable and useful?', *Linköping University Electronic Press*, Linköpings universitet, 2018, pp. 9–16. <http://dx.doi.org/10.3384/ecp181539>
- [6] E. Kharlamov, F. Martin-Recuerda, B. Perry, D. Cameron, R. Fjellheim, and A. Waaler, 'Towards Semantically Enhanced Digital Twins', in *2018 IEEE International Conference on Big Data (Big Data)*, Dec. 2018, pp. 4189–4193. doi: 10.1109/BigData.2018.8622503.
- [7] E. Fjøsna and A. Waaler, 'READI Information modelling framework (IMF). Asset Information Modelling Framework', READI Joint Industry Project, Oslo, Mar. 2021. [Online]. Available: <https://readi-jip.org/wp-content/uploads/2021/03/Information-modelling-framework-V1.pdf>
- [8] D. B. Cameron, A. Waaler, E. Fjøsna, M. Hole, and F. Psarommatis, 'A semantic systems engineering framework for zero-defect engineering and operations in the continuous process industries', *Front. Manuf. Technol.*, vol. 2, p. 945717, Sep. 2022, doi: 10.3389/fmtec.2022.945717.
- [9] D. B. Cameron, K. Falk, and S. (Satya) Kokkula, 'Towards Digital Requirements for Transformation in the Natural Resources Industries White Paper from the DSYNE Network Workshop, 9th-10th February 2021', University of Oslo, 2021. Accessed: Dec. 07, 2023. [Online]. Available: <https://www.duo.uio.no/handle/10852/89024>
- [10] R. Mehmandarov, A. Waaler, D. Cameron, R. Fjellheim, and T. B. Pettersen, 'A Semantic Approach to Identifier Management in Engineering Systems', in *2021 IEEE International Conference on Big Data (Big Data)*, Dec. 2021, pp. 4613–4616. doi: 10.1109/BigData52589.2021.9671515.
- [11] READI JIP, 'Reference Designation System for Oil and Gas – READI'. Accessed: Dec. 21, 2021. <https://readi-jip.org/reference-designation-system-for-oil-and-gas/>
- [12] D. B. Cameron et al., 'The Digital Design Basis. Demonstrating a framework to reduce costs and improve quality in early-phase design', *Digit. Chem. Eng.*, vol. 2, p. 100015, Mar. 2022, doi: 10.1016/j.dche.2022.100015.
- [13] D. B. Cameron, W. Otten, H. Temmen, M. Hole, and G. Tolksdorf, 'DEXPI process: Standardizing interoperable information for process design and analysis', *Comput. Chem. Eng.*, vol. 182, p. 108564, Mar. 2024, doi: 10.1016/j.compchemeng.2023.108564.
- [14] D. Cameron and T. Østerlie, 'SIRIUS: Collaboration Across the Digital Divides in The Oil and Gas Supply Chain', in *Practitioners Proceedings of the 2018 University-Industry Interaction Conference*, London, United Kingdom: UIIN, Jun. 2018, pp. 91–101.

4. Details of the impact

As noted above, the research and innovation work reported here built on the impact and industrial network established by the **Optique EU project** (2014-2016) [4]. The core network in Optique became central to the SIRIUS Centre for Research-Driven Innovation in 2015. Early in the life of the centre, it became clear that effort would be needed to ensure that fundamental IT research answered real business challenges of partner companies. SIRIUS thus established a **beacon program** on digital twins and digital field development [14]. This created a portfolio of projects with the explicit purpose of deriving impact from SIRIUS' research agenda for knowledge representation and graph databases.

The agenda for this work was set by workshops with SIRIUS partners (Equinor, DNV, SLB, IBM, SAP, OSISoft) and other companies (Siemens, Total, Shell, Aibel, Aker Solutions, TechnipFMC). We pursued a dissemination strategy that involved business-oriented presentations at events organized by NORWEP, EU PPPs (BDVA and SPIRE) and workshops in Rio de Janeiro and Houston. This resulted in PetWIN, a collaboration with Petrobras, Shell, Equinor and UFRGS, financed by the RCN and FINEP.

Collaboration with DNV and Equinor resulted in engagement with the **NORSOK Z-TI** project and its successor, the **READI Joint Industry project**. **The economic driver here was the potential to reduce procurement costs in field development by up to 20%.** Here the SIRIUS research team was a key provider of tools and ideas behind the implementation of the project. READI resulted in three deliverables: the ISO/IEC81346 RDS for oil & gas [11], IMF concept paper, and a semantic representation of requirements [9]. The work on requirements is being developed as a course program, staff exchanges and workshops with dissemination in Brazil and the US, through the DSYNE INPART network (<https://dsyne.no>).

The READI JIP identified the need for **IMF** as a tool to link the RDS for oil & gas to engineering data and requirements. IMF provides a rich information model that supports structuring of engineering data in an effective way that also supports reasoning about requirements [8]. At the same time, 2018, participants in READI, Aibel, Aker Solutions and TechnipFMC, became partners in SIRIUS.

This provided an opportunity for a further **Digital Design Basis JIP**, organized within SIRIUS, that attempted to model design bases from three operating companies (Equinor, Lundin and AkerBP) as semantic data, so that it could be used by three vendors (Aker Solutions, TechnipFMC and Aibel) [12]. This prototyping work informed software development by Aize AS, TechnipFMC, Equinor and Aibel. **Aker Solutions' business case for the project identified cost savings of at least NOK 1.6 billion a year across the Norwegian Continental Shelf just in early phase design.**

This work was followed up further by the **DISC initiative in the Yggdrasil field development**. This initiative is a collaboration between Equinor, AkerBP, Aker Solutions and Aibel, where operators and vendors agree to pilot new ways of transferring engineering data during a field development project, with the aim of moving away from document-based work processes. This initiative has validated the IMF, the RDS for oil & gas and IDO. In addition, the project has been a leading implementer of **Industry 4.0 standards** such as AutomationML, NAMUR, Asset Administration Shell and DEXPI. This has resulted in SIRIUS establishing new collaborations with German academia and industry, notably through the publication of an IMF-inspired DEXPI standard for process design data [13]. We have also developed a library of IMF types for design of facilities.

OTTR has also been adopted as a **tool by third parties**. The group of Prof. Melinda Hodkiewicz at the University of Western Australia uses the tool to manage ontologies of maintenance systems for mining companies (BHP and RioTinto) [3] and is active in the IDO work. Aibel, DNV, and Grundfos use

OTTR in their development. A recent start-up, Data Treehouse AS (<https://www.data-treehouse.com>), uses OTTR as a core technology in their products.

SIRIUS is among the founding members of the recently created Knowledge Graph Alliance (<https://www.kg-alliance.org/>) as one of the results of the OntoCommons EU project (<https://ontocommons.eu/>). IMF principles have been used in the development of the OntoCommons EcoSystem (OCES) and partially demonstrated in OntoCommons demonstrators. SIRIUS developed collaborations with Industrial Ontology Foundry (<https://oagi.org/pages/industrial-ontologies>) and organised, together with DNV, the first open workshop of IOF in Oslo in 2019 with about 120 participants.

SIRIUS methods are being applied and further developed in four ongoing Horizon Europe projects in the manufacturing sector with UiO as partner: Re4Dy (<https://re4dy.eu>), Plooto (<https://www.plooto-project.eu>), Tec4MaaSEs (<https://tec4maases.eu>), and Sm4rtenance (<https://sm4rtenance.eu>).

Initiatives ongoing to realize the full potential of this transformation include: (1) publication of IMF as a DNV Recommended Practice; (2) communication through the IOGP digital initiative <https://www.iogp.org/workstreams/engineering/standards/digitalization/> and CFIHOS <https://www.jip36-cfihos.org>; (3) collaboration with a revitalized POSC Caesar Association, who is developing IDO and also collaborating in the fPVN – Arrowhead EU project <https://fpvn.arrowhead.eu/fpvn-arrowhead/>; (4) participation in the new ISO standard ISO/NP 23726 Ontology Based Interoperability. IDO will be part 3 of this standard; (5) use of the DSYNE network to catalyze further work and support adoption in Brazil and the US; support of new and existing software vendors in the development of industrial-strength tooling; (6) contributions to standardization work in the Industrial Digital Twin Association, NAMUR and DEXPI and (7) collaboration with stakeholders in the electrical energy sector including Statnett and Statkraft, and construction sector to prove our methods as a unifying tool for discipline-specific data models, such as CIM and BIM.

Note that we have adopted a dual publication strategy. The fundamental research is published in the semantic technologies literature [2], [3], [10], whereas the translational and application work has been published in the relevant manufacturing [8] or chemical engineering [12], [13] literature. We also present at trade conferences, such as the annual NFEA Digitalization conferences.

5. Sources to corroborate the impact

See references 7-14 in section 3.

- OTTR website with open-source software: <https://ottr.xyz/>
- IMF website: <https://www.imfid.org>
- DEXPI Process <https://dexpi.org/dexpi-process-specification-1-0-released/>.
- POSC Caesar association https://www.posccaesar.org/projects_and_workgroups/
- READI JIP <https://readi-jip.org>

Personal references in collaborating companies:

- Jann Kåre Slettebakk, Vice President, Aker Solutions.
- Torleif Saltvedt, Senior Advisor Information Management, Equinor.
- Ellen C. Karlsen, Digitalisation and Improvement Manager, Aibel.
- Kirsten Helle, Manager Technical Safety & Reliability, TechnipFMC.
- Mikkel H. Brynildsen, Chief Data Scientist, Grundfos.
- Kjell Eriksson, Vice President, DNV.