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Abstract

This article presents the results of the third cycle of an Action Research (AR) study conducted in an offshore exploration and production (E&P) operator on the Norwegian Continental Shelf (NCS) that investigated a digital transformation in offshore E&P supply chain operations, with a focus on drilling operations. This study provides the results of a brief investigation of the main factors that contribute the success of digital transformations and demonstrates the value of using technology roadmapping alongside systems engineering (SE) practices to create a path between identified “AS-IS” and “TO-BE” operational states. Applying systems engineering methods to the adoption of the “T-Plan” roadmapping process resulted in a strategic communication tool that can be used among stakeholders to support them with the integration of business planning and technology adoption, and to help assess the impact that new technologies may have on their organizations in their journey toward a successful digital transformation. In addition to the roadmap itself, which benefits the case company, this study contributes to building and enriching academic literature by providing insight from the oil and gas industry and demonstrating the use of technology roadmapping to create a strategic plan for digital transformation in a well-established industrial domain.

Keywords/Index terms: Technology Roadmap, Digital Transformation, Exploration and Production, Offshore supply chain and drilling operations.

1. Introduction

The emphasis on data collection, digital collaboration, and digital technologies skyrocketed in the last few years among the operators and suppliers working in the offshore exploration and production (E&P) industry on the Norwegian Continental Shelf (NCS). Maintaining competitiveness, expanding operations, increasing safety, and reducing emissions and cost are perceived as the most important reasons for this new interest, as new demands and challenges are presented to the industry worldwide [1-4].

To succeed under new and challenging conditions, organizations must change and adapt, they must innovate, update their business and operating models, and adopt modern technology as needed. Digital technology includes electronic tools, automatic systems, and related devices and resources that acquire, process or store data. Cloud computing, the Internet of Things (IoT) and artificial intelligence (AI) are examples of digital technology. The reimagination of businesses through the adoption of digital technologies is referred to as Digital Transformation (DT), where digital technologies are adopted to create new or modify processes, cultural environments, organizations, and customer experiences to comply with the new and changing demands of society, governments, and markets[5-7]. A successful adoption of digital technologies depends on the creation and execution of a successful strategy, that is an action plan referred to as digital transformation strategy that guides an organization and positions it for success[8-10].

Czachorowski has conducted a longitudinal research of the supply chain activities executed to find and explore (e.g., drilling) offshore reservoirs in an offshore E&P Norwegian Operator on the NCS. She applied systems engineering methods to reveal that the current ("AS-IS") processes are conducted in organizational silos, via manual entries in legacy systems, without software interoperability. The research resulted in the identification of the desired future ("TO-BE") state of these activities and operations, which suggest that the adoption of digital technologies is needed to achieve the desired and improved supply chain work environment. In addition to efficiency, it is expected that digital technologies can promote safety, sustainability, and cost avoidance/reduction. These results are presented in Czachorowski et al.[11]

This study presents results from the the third and final action research cycle of the longitudinal research during which Czachorowski investigated alternative technologies for consideration to achieve efficiency, sustainability, and the progressive digital transformation of the offshore E&P supply chain for this company. A digital transformation strategy emerged to support transition from the current to the desired operational state. Systems engineering practices were applied to facilitate the creation of a technology roadmap based on the "T-Plan" methodology [12,13].

Robert Phaal has been instrumental in the maturation of technology roadmapping, with its close parallels to social systems engineering, and proposes three key questions that support a roadmap process: (1) Where do we want to go? (2) Where are we now? (3) How can we get there? [12-14].
Czachorowski et al.[11] offer the answer to the first two questions and present the system engineering methods applied in the preparation of systemigrams. This study addresses the third question, using information collected in the research to prepare a graphical representation in a roadmap that can serve as a cohesive strategic tool for communications between stakeholders and be used by business managers as a benchmark for their digital transformation journey.

This study continues with background information followed by a description of the research methods adopted, results, implications, contributions, and conclusions.

2. Background

This section provides an overview of the technology roadmapping and digital transformation literature, and a brief description of the application of systems engineering practices that underpin the methods and results presented in this study.

2.1. Technology roadmapping

Since its earliest inception in the 1960s, technology roadmapping has been a process for connecting the organizational silos and facilitating communication between industrial practitioners [15]. In an article on the history of roadmapping, the authors summarize its value as follows: "Roadmapping is what delivers results—not the roadmaps alone"[16(p25)]. An informal literature review around the word 'roadmapping' combined with a variety of filters, such as technology, product, strategic, and planning, deliver a plethora of articles on the process of roadmapping, including a multitude of experience reports, and recommendations for customization. The search results also revealed a gap in the literature that ties roadmapping to the oil and gas industry or the subsea domain. The most often cited sources of advice on the process for generating roadmaps come from the University of Cambridge and its Centre for Technology Management [17-19]. The literature selected for further scrutiny represents highly cited authors, but where multiple authors have collaborated over time to mature a concept, only the most recent article has been included, alongside a blend of bibliometric reviews and modern experience reports. From a sampling of 68 articles, it was possible to identify 5 generic categories as shown in Table 1. They are historical background, the process of generating roadmaps, and use of roadmapping for forecasting, planning, and product development.

Table 1. Summary of Roadmapping Literature Review.

Code	Authors	Topic area	Summary
Historical review	Kerr & Phaal [15]	20 years and earlier, retrospective	Roadmapping is a toolkit that emerged from practitioners not academics
	Probert & Radnor [16]	Viewing the future Part 1	Corporate roadmappers create value with product and technology roadmaps
	Radnor & Probert [20]	Viewing the future Part 2	Roadmapping is what delivers results—not the roadmaps alone

Code	Authors	Topic area	Summary
	Letaba, Pretorius & Pretorius [21]	Trends in technology roadmapping	An analysis of the life cycle pattern of scientific contributions over 3 generations
Process	Phaal [22]	Value of workshops	Consensus building
	Groenveld [23]	Roadmapping Integrates Business and Technology	Report from Phillips
	Phaal, Farrukh & Probert [24]	Technology management	Linking technology resources to business objectives
	Phaal, Farrukh & Probert [22]	Workshop approach	Exploring strategic issues and opportunities
	Kerr & Phaal [25]	Visualizing roadmaps – Fast Start	A process methodology can help craft roadmap visualizations that communicate plans and insights more effectively
	Parviainen, Tihinen, Kääriäinen, & Teppola [26]	Digitalization in practice	Approach to systematically implement digitalization and to take the steps necessary to benefit from it.
	Sebastian, Moloney, Ross & Fonstad et al.[27]	Technology-enabled assets are essential for executing a digital transformation: an operational backbone and a digital services platform	New digital technologies present both game-changing opportunities for—and existential threats to—'big old companies' whose success was built in the pre-digital economy; case studies
	Kerr, Phaal, & Thams[28]	Lego corporate experience	Process journey in customizing a reference process and the deployment of the approach
	Fellenstein & Umaganthan [29]	Keeping up with disruptive changes through business model innovation for logistics and transportation	Building dynamic capabilities for business model innovation towards the ongoing digital transformation
	Hillegas-Elting [30]	Practitioner's experience, SoS	Roadmapping serves as the research agenda-setting process
	Ho & O'Sullivan [31]	Functional Roadmaps Beyond Technology R&D	The development of skills, infrastructure, and standards; good case study and literature review; higher level integrated innovation roadmap focusing on broader contexts of innovation systems.

Code	Authors	Topic area	Summary
	Hirose, Phaal, Farrukh, Gerdsri, & Lee [32]	Roadmapping Implementation	Introduces a maturity model to guide the process of organization-wide roadmapping implementation. Report on industrial case studies
Foresight	Coates [33]	Scenarios and roadmapping as tools for forecasting	A look at the future with a view to anticipating what will happen and what needs to happen in order for the industry to move ahead
	Porter [34]	Scenarios and roadmapping as tools for forecasting	A call for better ways to use digital resources for technology monitoring, forecasting, and assessment
	Hussain, Tapinos, & Knight [35]	Scenario-driven roadmapping	A maturity model to guide the process of organization-wide roadmapping implementation
	Ringland, Ilevbare, Athanassopoulou, Greenaway, & Phaal[36]	Scenarios and roadmapping to navigate an uncertain future	Roadmapping for technology foresight provides a framework for investigating technology developments, interrelationships, and critical timescales
Product development	Lichtenthaler [37]	Integrated Roadmaps for Open Innovation	Implications to consider potential returns from a technology as a whole rather than from product sales alone
	Ghorbel, Kapusta, & Allen [38]	Roadmapping Workshop on the Development of AUVs	Consensus from Oil & Gas operators, service providers, policy makers and others of the anticipated needs and wishes for AUV technology in 10 years
	Kim et al. [39]	Design roadmapping	How DRM complements TRM and facilitates tradeoffs among strategic goals to address the feasibility, viability, and desirability of new product and service designs more comprehensively.
Planning framework	Nauda & Hall [40]	Roadmaps for competitive advantage	Coordination of business planning and technology investments planning efforts for sustainable competitive advantage

Code	Authors	Topic area	Summary
	Phaal, Farrukh, & Probert [41]	A planning framework	Focus for scanning the environment and a means of tracking the performance
	Cosner et al. [42]	Frequently cited, more than just technology	Integrating Roadmapping into Technical Planning; roadmapping must be coordinated across multiple, highly autonomous business units (product, market, strategic).
	Phaal & Muller [14]	Support for integrated strategic planning	Architectural framework for roadmapping: Towards a strategy for visualization. Used in this research.
	LaGrange [43]	Digital Lifecycle Approach to Offshore Oil and Gas Production	Integrated digital lifecycle approach designed to enable digital design and manufacturing, virtual testing and commissioning, and delivery of an intelligent "digital twin"
	LaGrange [44]	The Roadmap for Oil and Gas Optimization	Digital twins can be used to enhance efficiency in the wider context of the oil and gas industry – with a particular focus on reducing risk and cost during both the project and operational lifecycle phases
	Al-Ali & Phaal [45]	Roadmapping an agile digital transformation	Prototyping a first-cut digital transformation strategic roadmap
	Schimpf & Abele [46]	German companies experience	Implementation in face of new challenges (e.g., digitization)

Nauda & Hall [40] conceived of the roadmapping process as a means to systematically identify new technologies for future growth, coordinate the needs of many different business units, and determine a realistic allocation of resources (people, funds, and facilities), that can be integrated into the business planning and review cycle. Technology roadmapping has an established and proven track record for helping organizations with their strategy, long-term planning, innovation, and foresight activities [15]. In its modern form it embodies a temporal, multi-layered, systems-based approach to connect an “AS-IS” situation to its desired “TO-BE” state. Roadmapping is known to serve any number of purposes under different headings, from technology roadmapping, product roadmapping, business roadmapping or strategic roadmapping, but has its roots firmly embedded in industrial engineering.

The development of the method was led by practitioners and this is reflected in the advantages of deploying roadmapping, which "stem primarily from the combination of logical analysis, widespread consultation and discussion, and use of graphical techniques" [47(p21)]. Even as the methods have matured into a flexible, integrative, and powerful approach for business planning, "the technology-oriented prefix can be tactically and strategically unhelpful in terms of organizational acceptance and deployment of the method/tool" [15(p6)].

When used to formulate strategy and policies, technology roadmaps have proved useful in facilitating communication and learning and building consensus across a firm. Within a firm they assist by helping to operationalize the strategies by mapping the details of future research and development programs, technological capability development programs, professional skills training programs, and identifying areas of investment to address all the above [12,21].

A key benefit of roadmapping is the level of communication associated with the development and dissemination of roadmaps, particularly for aligning technology and commercial perspectives [48]. This study employed a workshop-based method for supporting the identification and exploration of strategic issues and opportunities, as part of a "fast-start" approach for the rapid initiation of roadmapping [22]. The 'fast-start' approach was developed to support a robust roadmapping process that can be deployed quickly and economically. The "T-Plan" methodology is an adaptation of the technology roadmapping process that fast-start the activity, beginning with the plans to define what will be investigated, followed by a four-workshop process that constitutes the roadmapping activity, and ending with the execution of the roadmapping itself [12]. Each of the four workshops treats one main domain of the roadmapping process, as follows: 1) identify the market domain, 2) focus on the involved product(s) or service(s), 3) focus on technology, and 4) construct the roadmapping visualization that links technology and market to deliver the product or service [12].

This study considers the use of the roadmaps from two main perspectives. The first is a company perspective: roadmaps that allow technology developments to be integrated with business planning and help assess the impact of new technologies and market developments. It is crucial to provide a framework for supporting effective dialogue and communication within and between organizations. The second perspective is multiorganizational: roadmaps that seek to capture the environmental landscape, threats, and opportunities for a particular group of stakeholders in a technology or application area. Two short illustrative cases from the literature show the fast-start method in use in the context of disruptive technological trends from these two perspectives [41,45].

The roadmapping approach is flexible and scalable and can be customized to suit many different strategic and innovation contexts. However, as the literature suggests, this demands careful planning and design, including consideration of roadmap structure, process, and participation. The structure of the roadmap, and the process for developing and maintaining the roadmap, should be designed to provide a "common language and structure" for both development and deployment of strategy [14].

2.2. System Engineering

Systems engineering has recently been defined as "a transdisciplinary approach that applies systems principles and concepts to enable the successful realization and use of engineered systems and whole-system solutions." [49]. A systems engineering (SE) approach to developing an organizational roadmap can help practitioners create an artifact with visual elements that support their unique communication goals. The SE process begins by eliciting the key information that needs to be conveyed by the roadmap, so that content can be aligned to organizational requirements. This distills a common voice and a set of consistent messages. The approach supports the design of tailored visual representations that can be used to present clear and meaningful narratives to specific stakeholders [14]. As a final step, and throughout the implementation process, systems engineering methods provide processes for conducting trade-off studies, preparing a robust testing and verification plan, and validating that the eventual solutions meet the needs of the organizational stakeholders.

2.3. Digital Transformation

A recent survey of the literature attempted to answer the question about the relationship between digital constituents and sustainability [50]. They identified the potential for digital technologies to drive resource efficiencies in sustainable businesses when they implement digital infrastructure and digital socio-technical environments that are consistent with the business models. They also identified a concept of digital readiness which implies the adoption of digital infrastructure elements as an enabler of digital transformation. An alternative view of digital transformation (DT) is offered by Schallmo, Williams, & Boardman [51(p4)].

The DT framework includes the networking of actors such as businesses and customers across all value-added chain segments, and the application of new technologies. As such, DT requires skills that involve the extraction and exchange of data as well as the analysis and conversion of that data into actionable information … to enable decisions and/or initiate activities.

Schallmo et al. [51] also suggest that adopting DT should follow a systemic and systematic process, analogous to SE and the SPADE framework of activities [52]. Accordingly, the process should begin with an understanding of the needs of the stakeholders and a clear formulation of the problems. Information gathered in these activities can serve as a starting point for the design of a digital business model for the future. Alternative models are tested against the stated needs to identify those that fulfil customer requirements and achieve the business objectives. Combinations of the options are evaluated until a final model is approved and the innovation and other changes are implemented. This is a highly iterative, circular process that should engage all stakeholders, notwithstanding the linearity in the description of the process [53]. Implementation usually takes the form of cascading projects that explore the digital landscape, test both the human and machine environment and the operational results and mitigate overall risk by allowing course corrections underway.

Westerman, Bonnet, & McAfee [54] advise organizations to assess their digital maturity to evaluate and decide which parts or elements of their business models may perceive the most benefit from the investment in digital transformation. Assessing the current digital maturity is a critical step to identify the starting point for a firm's DT. They propose that leaders who concentrate on transforming operational processes and business models can best realize benefits from updating their internal processes through infrastructure investments, worker enablement and performance management. Business model transformation involves redefining the way internal functions interact and evolving the boundaries and activities of the firm to include external collaborations. A technology roadmap is useful to guide management to select the key enabling technologies, determine the projects, and construct an optimized project portfolio under risk and schedule constraints in the planning horizon. A well-constructed DT strategy plan will address process and culture as well as technology dimensions including innovative IT and software systems that need to be developed and operational in tight time frames. This suggests a role for systems engineering in making digital transformations succeed.

3. Methods and Data Collection

This section presents the context of the participatory action research case study and the activities conducted in the third and final cycle of the AR. Progress from the first two cycles has been reported and those results form the basis for building a strategic roadmap for a digital transformation within the case company [11,55].

3.1. Action Research

Action Research (AR) is a methodology that integrates theory and practice to facilitate solving complex organizational or social problems. Participatory AR connects the researcher and the ones experiencing the problems [56–58]. Through simultaneous research and participation, AR supports theory and knowledge creation and problem-solving to achieve both practical and research objectives [59]. AR was initially proposed by Lewin [60] as a spiral of steps or cycles, and this study adopts the four-stage approach proposed by Kemmis, McTaggart, & Nixon [57].

The third and final cycle of the AR is the focus of this study. It started in the third quarter of 2020 and lasted until the first quarter of 2021 with the objective to identify alternatives and a create a digital transformation strategy plan to reach the desired "TO-BE" operational state. A strategic technology roadmap to visualize and support the DT plan emerged from the interactions between the diverse set of stakeholders involved in the study. The roadmap serves as a cohesive tool for communications and consensus building within the stakeholder community. The investigation was conducted during the Covid-19 world pandemic, which removed the possibility of having physical encounters with the stakeholders. Since all encounters were required to be virtual as a consequence, the researcher needed to consider alternate modes of workshopping to achieve the much-needed outcomes within the imposed study schedule limitations. Therefore, instead of having single full-day workshops as described in the "T-Plan" approach, many virtual shorter workshops and meetings were conducted within each domain in the roadmap process. Later, a combination of the information collected from each workshop was conducted per domain.

The four phases were adapted from Kemmis et al. [57], namely Plan, Act, Observe and Reflect, conducted sequentially as illustrated in Figure 1 and Figure 2. To reach the cycle's objective, each phase followed an objective and had a set of activities executed. Secondary qualitative data review and analysis occurred in the Plan and Act phases by revisiting the data collected in earlier study cycles to integrate relevant information previously collected. Two additional activities were conducted: (a) literature review and (b) workshops where participant observations were logged, and the data collected in each activity was analyzed at the end of the activity. General interactions (e.g., phone calls) and smaller meetings were also held to validate information from the workshops that could not be detailed due to time constraints and to talk to informants that could not join the workshops but were pointed as important to the objectives of the study during the workshops. The roadmapping process was executed in the Act phase, validated in the Observe phase, and the roadmap final drawing was done in the Reflect phase. During 2Q and 3Q 2021 activity was focused on dissemination of the results. The summary of the cycle and its activities are presented in Table 2, and the activities conducted are further described in section 3.2.

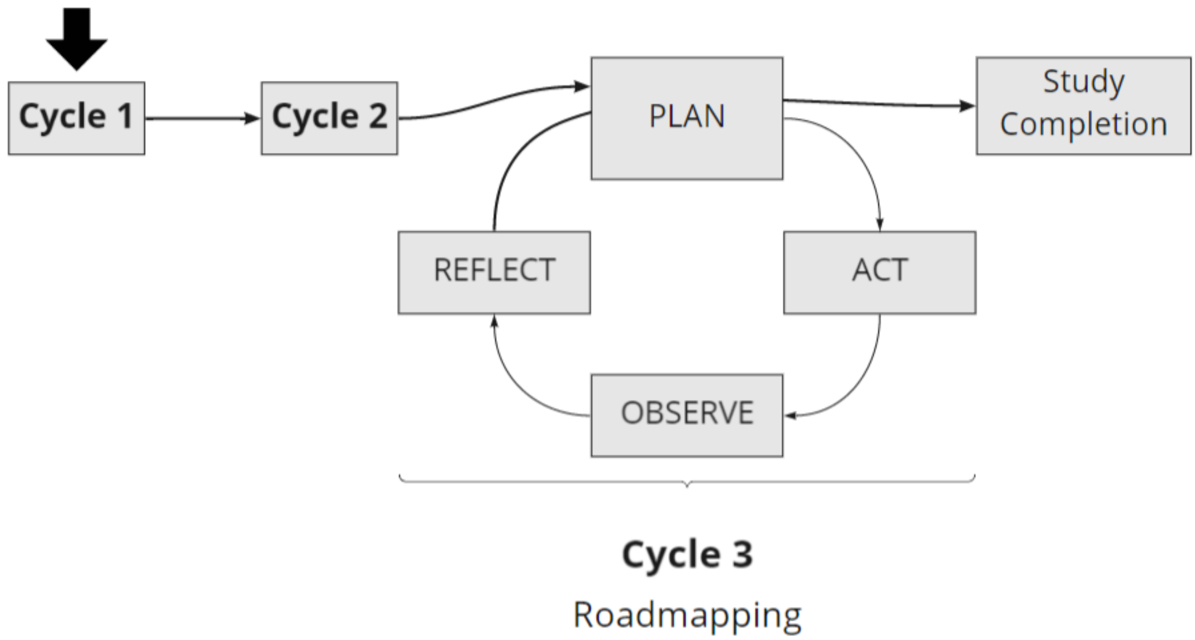

Figure 1. Czachorowski third cycle adapted from McAteer [61(p29)]

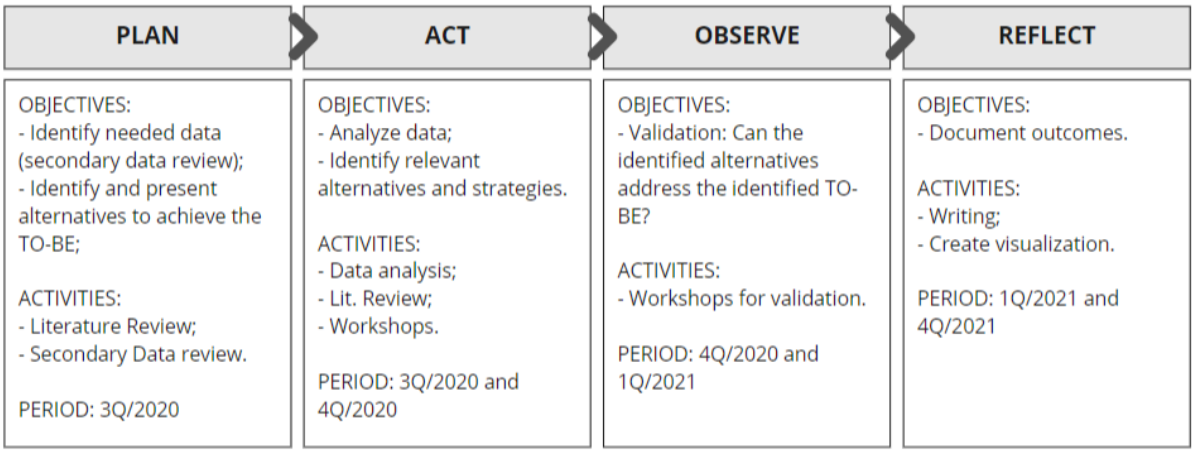

Figure 2. Czachorowski third cycle detailed (own authorship).

Table 2. Czachorowski cycle 3 - Detailed data collection and validation activities (data analysis and documentation excluded).

Cycle Stage	Year	Quarter	Nr. of general Interactions	Nr. of Workshops
Act	2020	Q3	10	1
Act	2020	Q4	9	3
Observe	2020	Q4	1	0
Observe	2021	Q1	1	1
TOTAL			21	5

3.2. Activities in Cycle 3

a. Literature review

An examination of peer-reviewed articles was conducted to review the existing literature related to the study's topic. Relevant articles were extracted from academic databases, such as Web of Knowledge and Scopus, and found using Boolean expressions with variations of these keywords: oil and gas, digitization, digital transformation, oil and gas digital, Norwegian oil and gas digital, technology, technology roadmapping. Additional reports by accredited institutions that research this industry and digital transformation were included in the review (e.g., DNV, KonKraft, Gartner, Capgemini, etc.). The results from this literature review were presented in section 2.

b. Workshops and interactions

As a consequence of the COVID-19 pandemic, physical encounters were not allowed by the Operator and the Norwegian authorities. Therefore, the workshops and interactions were conducted digitally via Microsoft Teams, and always included one or more Operator employee involved in the supply chain and drilling operations. The definition of a workshop is encounters of minimum 3 hours of extension and with at least 5 individuals. Additional meetings were scheduled to match the full-day contact time recommended by the “T-Plan” methodology. A total of 26 interaction and meetings were logged, and 5 workshops were conducted. In total, 20 individuals participated in at least one workshop and many participated in more than one. Seven of these individuals were new participants in the research, joining it in this cycle.

The workshops followed a recommended topic sequence that was used to collect and register information retrieved in the roadmapping process. These topics were: record the information in the roadmapping process. These domains were: (1) market, (2) service, (3) technology, and (4) roadmap. In the workshops, the participants explained the markets and operations from their perspective of how they envisioned ideal operations could be in the future in terms of technology, their priorities, and the risks they perceived towards pursuing a digital transformation of operations. A Miro board (miro.com), which is a cloud-based tool for designing in an interactive setting that worked as a digital whiteboard, was used to combine, and summarize the information collected from the informants and workshops, organized per domain. Table 3 shows the number of workshops and general interactions per domain registered per phase in the cycle, and the sequence of workshops and their scope is presented in Figure 3. In all except the first phase, the T-Plan “roll-out” contributed to the final roadmap presentation.

Table 3. Workshops (in parenthesis) and general interactions in Cycle 3 per phase and domain.

Phase	MARKET	SERVICE	TECNOLOGY	ROADMAP
ACT - Q3/20	5 (1)	3	3	0
ACT - Q4/20	0	3 (1)	6 (1)	3 (1)
OBSERVE - Q4/20	0	0	0	1
OBSERVE - Q1/21	0	0	0	2 (1)
Sub-total	**5 (1)**	**6 (1)**	**9 (1)**	**6 (2)**
Total:				**26 (5)**

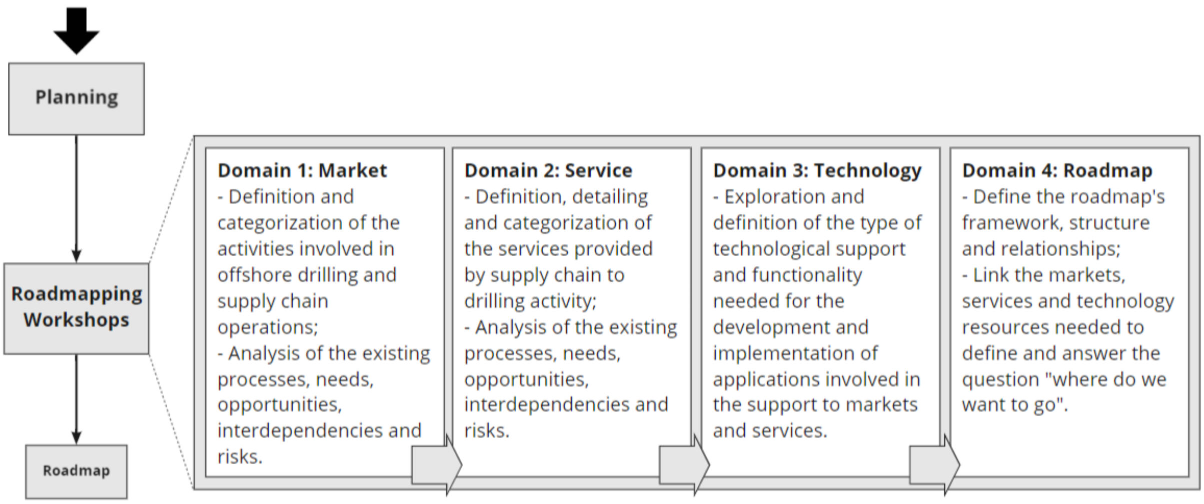

Figure 3. T-Plan methodology adapted from Phaal et al.[12]

3.3. Validation Activities in Cycle 3

During the Observe phase, a workshop and additional interactions took place to validate the researcher's understanding of the explanations and information that were given in relation to each domain. This validation occurred in form of questions, where the participants confirmed or rejected the information that was presented to them and indicated a new and correct information. Table 4 shows some examples of these questions and type of answers received. Likewise, the roadmap was presented to the individuals in these sessions to gather feedback and adjust it as needed. These sessions also permitted gathering additional and more detailed information about certain aspects of previously provided information that was not totally clear, or details that could not be pursued previously due to the time constraints of the workshops. Once these observations were collated, it was possible to assert that the proposed roadmap provided pathways that met the expectations of the workshop participants, as will be demonstrated in Section 4.

Table 4. Examples of questions and answers from validation activities.

Example of validation question	Example of received answer
By saying that automation is needed in SC: what part(s) of SC do you expect to be automated and which activities/tasks are you referring to? What is the business problem that automation is expected to solve?	I expect automation to reduce the number of manual interventions needed to gather information for the execution of purchase-to-pay processes (e.g., creation of purchase orders, invoices, payments). This type of automation can help to minimize data entry errors, increase the speed of information exchange, and reduce the overall number of overhead hours. It can also help to optimize activity planning based on real data.
Does the planning of resources begin prior to the selection of a concept for a well that is to be developed?	Some resources have longer production and delivery lead times, but at the same time, they are 80% standard from well to well. So, the planning of these items is based on the expectation of the well activity that is to come, with some fine tuning later in the process.
When certain technologies are described as a goal or desire, such as digital twins: what is it that you see a digital twin doing to SC? Any specific parts of SC? What is the business value that you expect to realize from the adoption of digital twins?	I expect to see a certain part or piece of an equipment that becomes yellow because its maintenance is due in a certain number of weeks. I also expect to see the lifecycle of that part, if maintenance has already been scheduled, if the part needs to be replaced, etc. If replacement is needed, I expect to see if it has been requested, purchased, if it is loaded for transportation, and see if the item will not arrive in time, because then I must react to it and try to find an alternative. I also expect to see the possible routes that a vessel can take to try to simulate the most efficient route, with the less CO2 emission, etc.

4. Results and Implications

As reported in the first dissemination of this research by Czachorowski et al. [11], the supply chain support operations for offshore drilling activities in the case company are fragmented into many different applications that do not interoperate and otherwise have limited data exchange. Operations engineers need to request, confirm, and approve the resources that are necessary to support offshore drilling activity execution (i.e., material, equipment, personnel). The operational data capture and exchange is mostly manual, and formal methods for data capture, curation and governance are not defined. To reach the desired "TO-BE" state where operations function smoothly requires constant data exchange in machine-understandable formats and software interoperability. Achieving this vision with an end-to-end perspective must include the whole value chain. Offshore drilling activity relies on data received from supply chain planning and execution support. At the same time, supply chain personnel must ensure that the partners and other suppliers involved in operations will deliver the necessary resources in the most efficient and least costly manner feasible, which relies on accurate planning and activity data from drilling activity coordinators (see Figure 4).

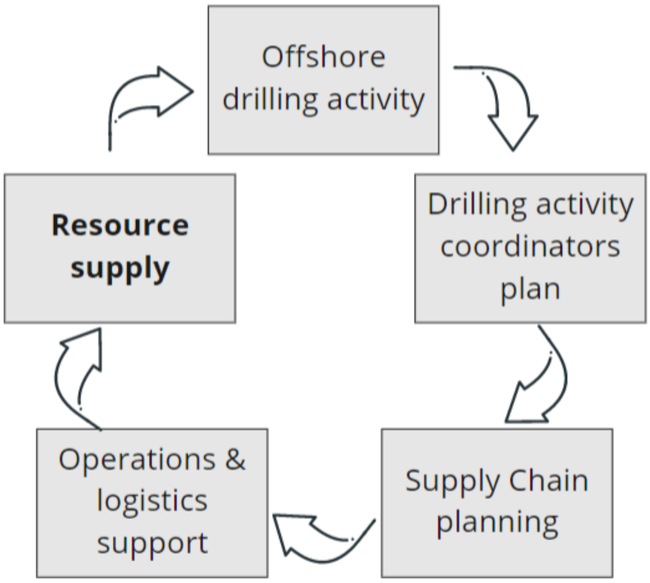

Figure 4. Illustration of the inter-related actors and activities (own authorship).

The workshops revealed a vision from the offshore drilling and supply chain personnel that conceives the creation of a simulation model able to use operational data from which the engineers can plan and see 3D visualizations of their own mental models of drilling activity, including supply chain operational support. The personnel from supply chain explained their view on optimal operations as a totally or almost totally automated system that uses the data created in the planning and progress of operational activities, such as drilling, to generate plans for the supply chain support that is needed to meet the operational demands. The data that results from operational activities can be used to calculate, predict, and simulate spend, overall cost, inventory use, logistical capacity, and to create forecasts of the expected support from external suppliers that can be shared so they can optimize their own operations and timelines. This way, supply chain can become pro-active instead of reactive, acting to improve conditions, contracts, and operational strategy instead of reacting to purchase requisitions and orders. Therefore, activity levels created and measured based on data become the drivers of supply chain support activity. These results are in line with the findings from the first two cycles discussed in Czachorowski et al. [11].

A digital transformation has begun at the case company to support these visions. Business and operating models are under review and adapted gradually, and tentative first prototypes of software and processes are being developed, replaced, improved, and eliminated at a large scale. With so many interdependencies, it can be difficult for management and other stakeholders to see "the big picture" and to steer toward the desired end-state. Uncertainty about "How do we get there?" jeopardizes the whole transformation, which would result in financial losses as well as the continuation of operations conducted below optimal capacity. Introducing a roadmapping process facilitates the liaison of the elements of the digital transformation and their relation to each other and the external domains involved. The resulting roadmap (Figure 5) presents a simplified graphical representation of the elements and their relationships, as well as a path to the future state to be achieved. The version used by the company is more specific and contains understandably confidential information. The roadmap presented in figure 5 adopts codes that replace the confidential information, and the detailed explanation of these codes are presented in table 5 in the following section.

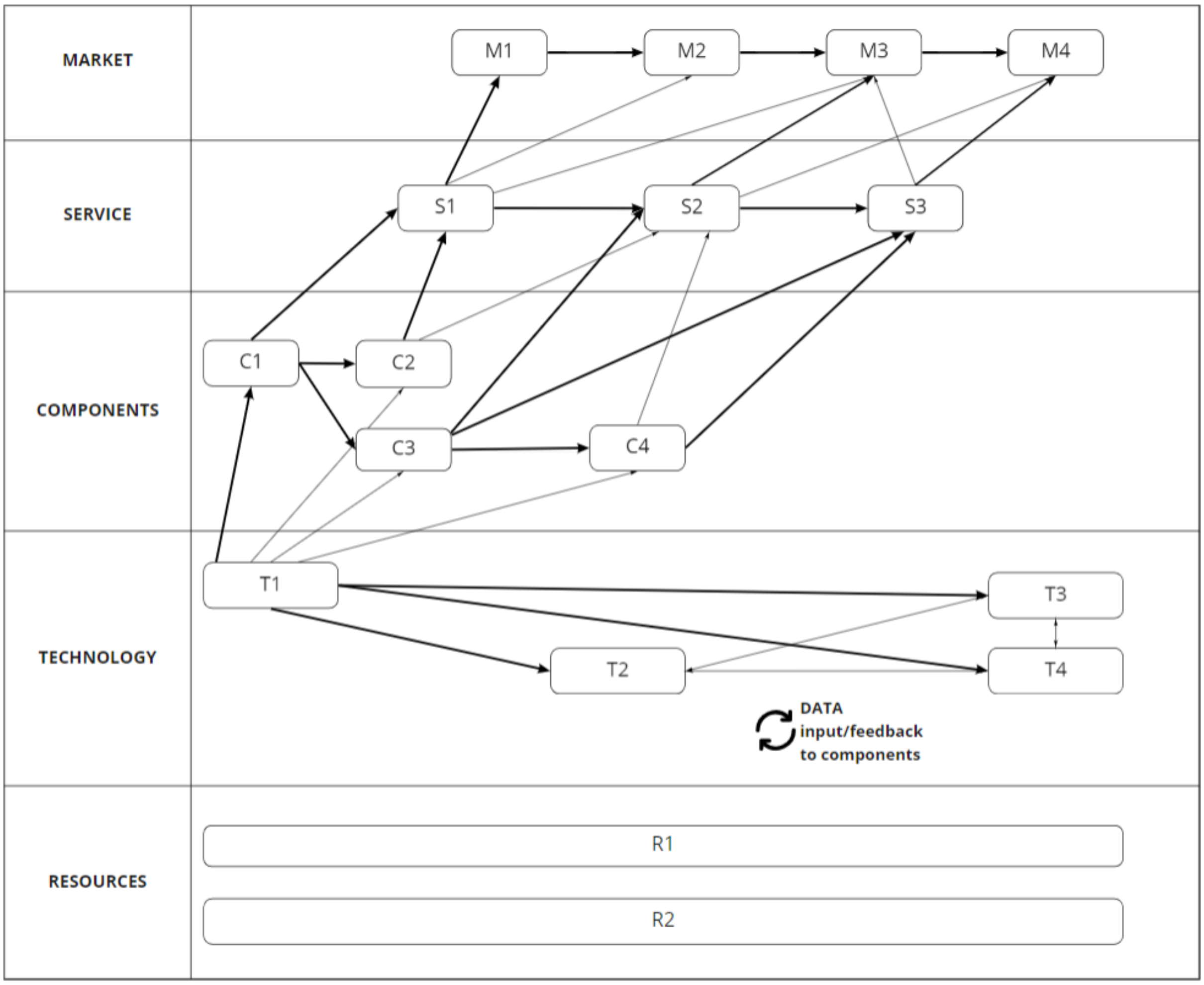

Figure 5. Final roadmap for drilling activities and supply chain support digital transformation (own authorship).

4.1 Roadmapping - Unit of analysis

The processes analyzed in the exploration and production drilling and supply chain operations were divided into groups called markets, services, components, technology, and resources, which comprise the units of analysis (Table 5) adopted by this study, as suggested by Phaal & Muller [14].

Table 5. Roadmap - Definition of the Units of Analysis, based on Phaal & Muller [14]

ID	Type	Description
M	Market (Internal Well Development and drilling activity Phases - support to Decision Gates (DGs) – from DG0 to DG4)	M1: Appraise & Select (SP) (DG0-DG1) M2: Plan and Select Well Concept (SP) (DG1-DG2) M3: Well Design and Execution Plan (P2P) (DG2-DG3) M4: Execute and Complete Well (P2P) (DG3-DG4)
S	Service (Services Provided by Supply Chain to Well Dev.)	S1: Strategic Planning (SP) S2: Purchase to Pay (P2P) S3: Logistics Operations (Log)
C	Components (Applications supporting the services and markets)	C1. Well Design and Planning C2. Time and Cost Estimation C3. Material and Personnel Resources Planning C4. Activity Planning and Execution Management
T	Technology (Technology supporting applications and their interconnection)	T1. Interoperability layer T1.1. API Management T1.2. Graph and SQL database T1.3. Cloud service T2: Data Science and automation T2.1. Business Intelligence – Data analysis T2.2. Machine Learning/Artificial Learning T2.3. Internet of Things (IoT) T3: Digital Twin T4: Ledger Technology – Blockchain
R	Resources (Supporting resources)	R1: IT support R2: Organization (HR and culture)

The well drilling activity includes well development and construction processes that start with the offshore field appraisal phase and ends at the drilling execution and completion. These processes are conducted in many phases, which can be divided into four markets (see Table 5). These markets are started and completed with a decision-making process defined as a “decision gate” (DG) that will define whether the next market opportunity will be pursued. The first market, called Appraise and Select (M1), starts at DG0 and ends at DG1. In this market, offshore geo-data is appraised, usually purchased from third parties, and used to determine which method will be applied towards the establishment of platforms and/or drilling of well(s) in that area. Examples of data are depth, water temperature, currents, type of soil, pressure, etc. Once the method(s) are defined (e.g., jack-up rigs, semi-submersible rigs, etc.), initial partners and vendors are selected and DG1 is reached. The next market, called Plan and Select Well Concept (M2), starts detailing and selects the well construction plans for the future well drilling based on the previous market’s method decision. Here, the well construction is detailed in engineering schematics that include fine detailing of drilling direction and trajectory, type of resources needed for the drilling execution and estimates the time and costs expected for the drilling. Partners and vendors involved in this market play a key role and provide most of the data involving these resources and estimations. Once the well construction plans are considered sufficient, DG2 is reached. Upon approval, the next market begins, called Well Design and Execution Plan (M3). In this market, the well planning is decomposed further into tasks and activities to be executed for the well construction and drilling, starting with the transportation of the rig to the drilling location all the way to the conclusion of well drilling execution. Resources needed in this phase are requested, purchased, rented, and transported (in case of long-transit items). Personnel involved in the plans are confirmed to determine their offshore housing and transportation booking. DG3 is reached at this stage, and if everything is approved, the actual well drilling and construction execution begins, beginning the fourth market, called Execute and Complete Well (M4). In this market, the well construction and drilling are executed with the full support of supply chain operations for its completion. Once completed, DG4 is reached, and the well is handed over to operations maintenance.

Supply chain operations engineers support these markets from beginning to end, but to a varied degree. This support is divided into three services (see Table 5). The first service, called Strategic Planning (S1), supports markets 1, 2 and 3 through the negotiations and contracts with partners, vendors, contractors, and other necessary acquisition, such as geo-data, software and long lead time items that have a longer production and/or delivery time. The relationship with suppliers is a major focus at this stage as their input and collaboration is key to the success of the drilling plans and execution. The second service, called Purchase to Pay (S2), supports markets 3 and 4. This service constitutes the more traditional transactional supply chain starting at purchasing with purchase requisitions and purchase orders, goods receipts, and service entries and finally the support to the invoicing and payment processes. The third service, called Logistics Operations (S3) also supports markets 3 and 4, with a heavy focus on delivering the resources needed for the drilling execution on time, and returning everything that must come back onshore upon execution completion.

Many software, tools and applications support these markets and services. These are divided into four major groups referred to as components (see Table 5) based on their type of support and subsequently mapped to the markets and services. These components are a mix of standard software already implemented (e.g., ERP system) and others that are in development solely for the purpose of supporting the well construction and drilling process. The first component, called Well Design and Planning (C1) consists of applications that (i) support the analysis and visualization of geo-data and related location characteristics; (ii) support the designing of platforms and well schematics based on the input from other business units (i.e. exploration), technical data and specifications provided by the suppliers and partners involved in this process (e.g. cement volume, equipment dimensions, casing measurements, etc.); (iii) support the 3D visualization of drawings and schematics and their interaction with their environment (e.g. type of soil, pressure, etc.). Component C1 supports S1 and M1, M2 and

M3 as indicated by connecting arrows on Figure 5. The second component, called Time and Cost Estimation (C2), consists of applications used to estimate the times needed for each phase of the well construction process and their cost, based on the resources needed for each phase. Component C2 provides crucial information to S1 to support the decision-making (DG) processes, and also supports S2, and thereby supports all the markets. The third component, called Material and Personnel Resources Planning (C3), maps the resources needed to complete the drilling plans to the plans themselves, thereby supporting the initiation of the Purchase to Pay processes supported in Service 2. This third component is crucial as it links the planning stages with M3, activating requisitions, purchases, and transportation. Finally, the fourth component, called Activity Planning and Execution Management (C4), consists of two applications (i) that support the fine detailing of plans into activities to be conducted, including resource information and (ii) that allow conducting the drilling execution offshore and a final report of their findings and results. These include the material and equipment orders, transportation, usage, return, personnel, and trigger the final part of the Purchase to Pay processes, providing input for invoicing and payment.

Components require underlying technology to achieve their objectives. Technology is divided into four groups, from T1 to T4, where T1 and T2 are subdivided further into three groups each (see Table 5). The main technology group, T1, is also the most important since it provides the databases that serve the applications and the technology used as the integration layer that supports interoperability among all other applications for data exchange. T1 is subdivided into Application Programming Interface (API) Management (T1.1), Graph and SQL databases (T1.2) and cloud service (T1.3). All the applications utilized in this group support a multi-cloud capability and provide standard APIs for data exchange. Some application's databases are based on SQL language, with a few transitioning to Graph as it provides more processing speed [62].

The second technology group (T2) includes data science and automation support. This group constitutes technology, software and applications related to the analysis, interpretation, visualization, and re-utilization of data in the processes and operational workflows executed. T2 depends heavily on the capabilities provided by T1 and is subdivided into Data Analysis and Business Intelligence (T2.1), Machine Learning (ML) and Artificial Intelligence (AI) (T2.2) and Internet of Things (IoT) (T2.3). The first sub-group relates to the traditional data reporting for the assembly and visualization of performance indicators and overall operational insights that can be extracted from the combination of different data sets (e.g., operational cost, CO_2 emission levels from marine operations, etc.). It also includes operational data that serve as status update and operation execution (e.g., items delivered, activity executed, etc.). The second sub-group refers to the usage of data and applications to automate tasks and provide suggestions based on data through the adoption of ML/AI in specific areas (e.g., cost reduction opportunities through the suggestion of less expensive items, vendors or routes; cargo allocation in vessels for optimal transportation; etc.). Finally, the third sub-group refers to the usage of IoT to automate operations by triggering certain actions upon the completion of pre-defined specific tasks set as pre-requisites (e.g., the payment of an invoice upon the item's delivery to the offshore platform based on the recognition of a sensor-like device on the item or its packaging). The combination of these sub-groups is also expected in certain parts of operations.

The third technology group (T3) relates to the setup of a Digital Twin. This group is dependent on receiving data and information from both T1 and T2 to operate and be reliable. A properly setup digital twin can provide the ideal visualization to support the operational follow-up and the simulations that are part of the vision for the operator's digital ecosystem. Yet, no operator functions alone - there are many external stakeholders involved in daily operations. While certain stakeholders are more strategic to operations due to specific agreements, partnerships or type of service/product provided, many others are transactional, meaning that they are seldom activated. For the strategic stakeholders, it makes sense to send and receive data seamlessly, through strategic integrations that facilitate the digital vision in question. For the non-strategic stakeholders, however, another solution must be found that does not involve the manual transaction of data or jeopardize the security of the digital ecosystem by providing too much access to key software to too many people. One possible solution for this problem is the adoption of a ledger-based technology such as Blockchain, which is our fourth technology group (T4). Blockchain a decentralized and distributed, tamper-resistant shared ledger that works based on a peer-to-peer verification process to reach consensus among the network and accept the transactions. The blocks are connected among themselves, so if one block is altered, the whole chain will be broken [63]. Therefore, such technology has the potential to support the exchange of data among stakeholders without the need for them to have access to internal systems or manual input [64].

The final group identified in the roadmapping process is the supporting resources group, divided into two sub-groups (see Table 5). The first, called IT Support (R1), includes all the support related to the infrastructure necessary to support all the other groups, the software, and applications in the components and to assure cyber security. This is a governance activity that includes the management of user roles and access to applications, management of physical assets, such as computers, screens, and similar, and management of internet access both onshore and offshore. Finally, the group is responsible for the critically important management of firewalls and other cyber measures utilized to maintain the system free from attacks, sabotage, possible information leakages, and downtime. The second sub-group, called Organization (R2), includes the people and culture aspects involved in the digital ecosystem including relevant stakeholders. These two aspects are important drivers and potential barriers of success in this digital transformation pursued by the case company, as people are an important part of the ecosystem as a whole. The way people interact with the current ecosystem is to be transformed into something that most people have not yet experienced, so it can possibly create resistance and anxiety towards the new ecosystem due to the uncertainties that it represents. Another factor of resistance is the possible lack of trust in the new system; hence, this needs to be mitigated so that the people involved can be able to trust that the new ecosystem is reliable, and therefore, accept it as their new way of working. At the same time, many people are keen on innovation, technology, and the thought of changing how they work, transforming them into champions for the transformation success. Identifying in which group the organization's people belong is important to mitigate the barriers and encourage the champions, thus increasing the chances of success.

4.2 Criteria for selection of technology

Many important decisions remain to be made regarding selection of technology and the introduction into the organization. A staggered introduction based on the priorities established by following the roadmap is useful to help mitigate the aforementioned barriers to acceptance. Another mitigating technique is to conduct thoughtful trade-off studies on the technologies before selecting an application to install as either final or prototypical solutions. Studies that involve the stakeholders in this selection process empower the employees to connect to the processes and the technological support tools. The case company has been gradually introducing technologies as proof-of-concepts while working toward minimal viable products. The technology related items' selection was guided by the technology, IT and architecture principles approved and communicated in the case company (see Table 6).

Table 6. Operator's general architectural principles (from the E&P Operator).

ID	Principle	Description
1	Security by design	Software and integrations are designed to be secure. Compliance to the company's list of security controls is mandatory for all digital solutions according to the data-classification they store, transfer or processes.
2	Off-the-shelf / as-a-service	Cloud based / cloud agnostic, commercially available off-the-shelf, as-a-service software is preferred to tailor-making.
3	Right place, time, and quality	Master data ownership and management ensure data has the right quality, is distributed from the right source and is available whenever needed.
4	Interoperability	Data flows in standard formats via standard protocols, in an event-driven fashion whenever possible, to ensure modularity, loose coupling and multi-cloud compatibility.
5	Convergent evolution	Business domains solution landscapes evolve independently but shall adopt common guidelines to adapt to the enterprise-wide ecosystem.
6	Collaboration	Data is liberated and accessible to all parties that play a role in our ecosystem to allow for a distributed, adaptive, and open environment.

It is very difficult to find commercial off-the-shelf (COTS) and as-a-service software (SaaS) that supports the operations needs and vision, and all the security, interoperability, and collaboration desired, and therefore, a significant amount of tailoring and customization is anticipated. Notably, in the selection, adoption and development of technology and applications, security is the strongest feature desired. The focus on security trumps functionality, user-friendliness and data exchange if needed, with the intention to actively stop any connections and data-exchange requests that are not pre-accepted by firewall configurations. Therefore, consequences arise in relation to software development, implementation and to interoperability, user-friendliness, and collaboration (data accessibility). Due to extremely high firewall security levels, all APIs need to be examined when implementing new software and given extra attention when developing it, which in turn increases time and resources. Reduced user-friendliness (e.g., automatic sign-off, 2-step verifications for logins, not saving passwords, etc.) may result in reduced user interest or increase the barriers for acceptance of new technology and software. The same applies to collaboration, as data available in one software might not be easily or completely available in another for security reasons. As a result, users might continue to need to login to multiple software and input data manually, compromising data quality and availability.

4.3 Contributions

The contributions from this study are multiple. The first and main contribution is the creation of the strategic roadmap, the explanation of how it was derived, and the considerations (e.g., technologies, digital tools, etc.) pursued and discussed during the process of roadmapping. This is important because having a practical example of TRM application can help strengthen the SE and TRM literature in three ways: (1) demonstrating the applicability of systems thinking and systems engineering practices to establish the endpoints of the "AS-IS"/"TO-BE" continuum necessary for the creation of a roadmap, (2) filling the gap of applications of SE to TRM, and (3) demonstrating the value of the adoption of SE methods and TRM techniques within the oil and gas industry.

A secondary, but no less important contribution is the utilization of AR theory and methodology to validate the soundness and applicability of the adoption of SE and TRM. AR fosters the experimentation and iteration between researchers and professionals, allowing the researcher to intervene in a problem domain and validate the outcomes of such intervention and to verify the effects of this intervention over time [65]. Moreover, AR helps organizations to address problems and contribute to academic knowledge creation at the same time [66]. In this study, these aspects of AR were instrumental in checking whether the SE and TRM processes and the final roadmap established a reasonable and sound plan for the digital transitions. This use of AR, in turn, strengthens the theory of Action Research by showing how theory is generated and enriched by practical results, instead of the notion that only theory informs practice [67].

5. Conclusion

The foundation of this study's design and execution was based on systems engineering methods and approaches that supported the elicitation of stakeholders' needs during workshops and the confluence of the diverse data collected through the application of techniques, such as systemigrams. SE tools facilitated reaching consensus within the different stakeholders' perspectives and identifying and understanding the root causes of underlying problems within the organization.

Understanding in-depth how digital technologies can be applied and how they impact the organization and industry is critical to succeed with digital transformation. It is important to understand the goals explicitly, before adopting digital technologies and tools, and the processes that will be affected by this adoption. In addition, it is critical to have a clear vision of a desired end-state after the adoption and implementation of the digital technologies and solutions. Without this vision it is impractical to conceive of a suitable strategy, which needs to consider the organization holistically to unify all the aspects involving a digital transformation, and not only technology. At the same time, the strategy must be successfully communicated and managed across business units, management, top-leadership and involved stakeholders. Adopting digital technology takes time, is costly, and demands long-term efforts. Organizations change over time and successful transformations are rolled-out thoughtfully over time, with risks mitigated along the way. Therefore, the success of digital transformations also relies on organizations maintaining and adapting their business and operating models, to achieve consistency between technology and business strategies and goals, and ultimately a sustainable competitive advantage.

The research presented in this study resulted in a strategic technology roadmap for the continuous digital transformation of the case company's supply chain activities with a focus on drilling operations. The E&P operator's ultimate goal is for planning and activity execution data to feed their operations applications automatically and as input to other technologies used for simulations and visualization. In this vision of the end-state the software and applications involved in the process become interoperable and operations are triggered by data (e.g., an action that is triggered by an equipment as it reaches a pre-defined target or threshold). This new way of working means that the humans involved in the execution of activities would no longer need to manually interfere in operations (or as minimally as possible) to perform simple or operational tasks (e.g., input data in applications) and could start simulating operations based on the available data, performing sensitivity analysis on the parameters, and taking decisions based on simulation recommendations and results.

This study's contributions include the adoption of SE methods and TRM techniques in the oil and gas industry, addressing a gap in existing academic literature on this topic and domain. The study's contributions continue with the adoption of AR, which strengthens AR by demonstrating how the methodology can support building sound theory from practice. Future research is suggested to be a return to the E&P operator to verify how much development and implementation has taken place and to evaluate whether these contributed to achieve the desired "TO-BE" visionary end-state.

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References

1. Forbes-Cable M, Liu W. Digital disruption: upstream supply chain threats and opportunities. Wood Mackenzie. https://www.woodmac.com/reports/upstream-oil-and-gas-digital-disruption-upstream-supply-chain-threats-and-opportunities-310260/. Published 2019.

2. World Economic Forum, Accenture. Digital Transformation Initiative - Oil and Gas Industry. http://reports.weforum.org/digital-transformation. Published 2017.

3. Fitz et al. How Digital Will Transform the Upstream Oil Ecosystem. Bost Consult Gr. 2018:2017-2108.

4. KonKraft. Project "Competitiveness – Changing Tide on the Norwegian Continental Shelf."; 2018.

5. Berman SJ. Digital transformation: Opportunities to create new business models. Strateg Leadersh. 2012;40(2):16-24. doi:10.1108/10878571211209314

6. Gobble MAM. Digitalization, Digitization, and Innovation. Res Technol Manag. 2018;61(4):56-59. doi:10.1080/08956308.2018.1471280

7. Bouncken RB, Kraus S, Roig-Tierno N. Knowledge- and innovation-based business models for future growth: digitalized business models and portfolio considerations. Rev Manag Sci. 2019;(0123456789). doi:10.1007/s11846-019-00366-z

8. De la Boutetière H, Montagner A, Reich A. Unlocking success in digital transformations. McKinsey&Company. 2018;(October):1-14.

9. Matt C, Hess T, Benlian A. Digital Transformation Strategies. Bus Inf Syst Eng. 2015;57(5):339-343. doi:10.1007/s12599-015-0401-5

10. Gobble MAM. Digital Strategy and Digital Transformation. Res Technol Manag. 2018;61(5):66-71. doi:10.1080/08956308.2018.1495969

11. Czachorowski K V., Haskins C, Mansouri M. Minding the gap between the front and back offices: A systemic analysis of the offshore oil and gas upstream supply chain for framing digital transformation. Forthcoming. 2021.

12. Phaal R, Farrukh CJP, Probert DR. T-Plan: The Fast-Start to Technology Roadmapping - Planning Your Route to Success. Institute for Manufacturing, University of Cambridge; 2001.

13. Phaal R, Farrukh C, Probert DR. Fast-Start Roadmapping Workshop Approaches. (M. M, R. I, R P, eds.). Berlin, Heidelberg: Springer; 2013. doi:doi.org/10.1007/978-3-642-33923-3_6

14. Phaal R, Muller G. An architectural framework for roadmapping: Towards visual strategy. Technol Forecast Soc Change. 2009;76(1):39-49. doi:10.1016/j.techfore.2008.03.018

15. Kerr C, Phaal R. Technology roadmapping: Industrial roots, forgotten history and unknown origins. Technol Forecast Soc Change. 2020;155(April):119967. doi:10.1016/j.techfore.2020.119967

16. Probert D, Radnor M. Frontier experiences from industry-academia consortia. Res Technol Manag. 2003;46(2):27-30. doi:10.1080/08956308.2003.11671551

17. Park H, Phaal R, Ho JY, O'Sullivan E. Twenty years of technology and strategic roadmapping research: A school of thought perspective. Technol Forecast Soc Change. 2020;154(February):119965. doi:10.1016/j.techfore.2020.119965

18. Singh S, Dhir S, Das VM, Sharma A. Bibliometric overview of the Technological Forecasting and Social Change journal: Analysis from 1970 to 2018. Technol Forecast Soc Change. 2020;154(January):119963. doi:10.1016/j.techfore.2020.119963

19. Sarin S, Haon C, Belkhouja M, et al. Uncovering the knowledge flows and intellectual structures of research in Technological Forecasting and Social Change: A journey through history. Technol Forecast Soc Change. 2020;160(July):120210. doi:10.1016/j.techfore.2020.120210

20. Radnor M, Probert DR. Viewing the future. Res Technol Manag. 2004;47(2):25-26. doi:10.1080/08956308.2004.11671615

21. Letaba P, Pretorius MW, Pretorius L. Analysis of the intellectual structure and evolution of technology roadmapping literature. In: Portland International Conference on Management of Engineering and Technology. ; 2015:2248-2254.

22. Phaal, Farrukh, Probert. Strategic Roadmapping: A Workshop-based Approach for Identifying and Exploring Strategic Issues and Opportunities. Eng Manag J. 2007;19(1):3-12. doi:10.1080/10429247.2007.11431716

23. Groenveld P. Roadmapping Integrates Business and Technology. Res Manag. 1997;40:5. doi:10.1080/08956308.1997.11671157

24. Phaal R, Farrukh C, Probert DR. Technology Roadmapping: Linking Technology Resources to Business Objectives.; 2001.

25. Kerr C, Phaal R. Visualizing roadmaps: A design-driven approach. Res Technol Manag. 2015;58(4):45-54. doi:10.5437/08956308X5804253

26. Parviainen P, Tihinen M, Kääriäinen J, Teppola S. Tackling the digitalization challenge: How to benefit from digitalization in practice. Int J Inf Syst Proj Manag. 2017;5(1):63-77. doi:10.12821/ijispm050104

27. Sebastian IM, Moloney KG, Ross JW, Fonstad N, Beath C, Mocker M. How big old companies navigate digital transformation. MIS Q Exec. 2017;16(3):197-213.

28. Kerr C, Phaal R, Thams K. Customising and deploying roadmapping in an organisational setting: The LEGO Group experience. J Eng Technol Manag. 2019;52:48-60.

29. Fellenstein J, Umaganthan A. Digital Transformation: How enterprises build dynamic capabilities for business model innovation - A multiple-case study within the logistics and transportation industry. Jonkoping Univ. 2019.

30. Hillegas-Elting JV. Pursuing “Fit for Purpose”: An Industry Practioner’s Experience with Roadmapping. IEEE Trans Eng Manag. 2020;September:1-12. doi:10.1109/TEM.2020.3024559

31. Ho JY, O’Sullivan E. Toward Integrated Innovation Roadmapping: Lessons from Multiple Functional Roadmaps Beyond Technology R&D. IEEE Trans Eng Manag. 2020.

32. Hirose Y, Phaal R, Farrukh C, Gerdsri N, Lee S. Characterizing Maturity Levels for Organization-Wide Roadmapping Implementation. IEEE Eng Manag Rev. 2020;48(4):133-143.

33. Coates JF. Boom time in forecastingNo Title. Technol Forecast Soc Change. 1999;(62):37-40.

34. Porter AL. Tech forecasting: an empirical perspective. Technol Forecast Soc Chang. 1999;62:19-28.

35. Hussain M, Tapinos E, Knight L. Scenario-driven roadmapping for technology foresight. Technol Forecast Soc Change. 2017;124:160-177.

36. Ringland G, Ilevbare I, Athanassopoulou N, Greenaway AM, Phaal R. Scenarios and Roadmapping-How to Navigate an Uncertain Future.; 2020. doi:10.17863/CAM.54145

37. Lichtenthaler U. Integrated Roadmaps for Open Innovation. Res Manag. 2008;51(3):45-49. doi:10.1080/08956308.2008.11657504

38. Ghorbel FH, Kapusta S, Allen J. An ideation and roadmapping workshop on the development of AUVs for oil & gas subsea applications. In: Offshore Technology Conference. Houston, Texas; 2019. doi:https://doi.org/10.4043/29671-MS

39. Kim E, Simonse LW, Beckman SL, et al. User-Centered Design Roadmapping: Anchoring Roadmapping in Customer Value Before Technology Selection. IEEE Trans Eng Manag. 2020:1-18. doi:10.1109/TEM.2020.3030172

40. Nauda A, Hall DL. Strategic technology planning-developing roadmaps for competitive advantage. In: Technology Management : The New International Language. ; 1991:745-748. doi:10.1109/PICMET.1991.183788

41. Phaal, Farrukh, Probert. Technology roadmapping—A planning framework for evolution and revolution. Technol Forecast Soc Change. 2004;71(1):5-26. doi:https://doi.org/10.1016/S0040-1625(03)00072-6

42. Cosner RR, Hynds EJ, Fusfeld AR, Loweth C V., Scouten C, Albright R. Integrating roadmapping into technical planning. Res Technol Manag. 2007;50(6):31-48. doi:10.1080/08956308.2007.11657471

43. LaGrange E. A roadmap for adopting a digital lifecycle approach to offshore oil and gas production. In: Offshore Technology Conference. Houston, Texas, USA; 2018. doi:doi.org/10.4043/28669-MS

44. LaGrange E. Developing a digital twin: The roadmap for oil and gas optimization. In: SPE Offshore Europe Conference and Exhibition. Aberdeen, UK: Society of Petroleum Engineers; 2019. doi:doi.org/10.2118/195790-MS

45. Al-Ali AG, Phaal R. Design sprints for roadmapping an agile digital transformation. In: 2019 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC). ; 2019:1-6.

46. Schimpf S, Abele T. How German companies apply roadmapping: Evidence from an empirical study. J Eng Technol Manag. 2019;52:74-88.

47. Barker D, Smith DJ. Technology foresight using roadmaps. Long Range Plann. 1995;28(2):21-28.

48. Willyard CH, McClees CW. Motorola's technology roadmap process. Res Manage. 1987;30(5):13-19.

49. Sillitto H, Martin J, McKinney D, et al. Systems Engineering and System Definitions. Vol 1.; 2019.

50. Bican PM, Brem A. Digital Business Model, Digital Transformation, Digital Entrepreneurship: Is There A Sustainable "Digital"? Sustain . 2020;12(13). doi:10.3390/su12135239

51. Schallmo D, Williams CA, Boardman L. Digital transformation of business models—best practice, enablers, and roadmap. Digit Disruptive Innov. 2020:119-138.

52. Haskins C. Systems Engineering Analyzed, Synthesized, and Applied to Sustainable Industrial Park Development.; 2008.

53. Plekhanov D, Netland T. Digitalisation stages in firms: towards a framework. 26th EurOMA Conf. 2019.

54. Westerman G, Bonnet D, McAfee A. The nine elements of digital transformation. MIT Sloan Manag Rev. March 2014:55 (1-6).

55. Czachorowski K V. Cleaning Up Our Act: Systems Engineering to Promote Business Model Innovation for the Offshore Exploration and Production Supply Chain Operations. Sustainability. 2021;13(4). doi:10.3390/su13042113

56. Baskerville RL, Wood-Harper AT. A critical perspective on action research as a method for information systems research. Enacting Res Methods Inf Syst Vol 2. 2016;2:169-190. doi:10.1007/978-3-319-29269-4_7

57. Kemmis S, McTaggart R, Nixon R. The Action Research Planner. 3rd ed. Singapore: Springer Singapore; 2014. doi:10.1007/978-981-4560-67-2

58. Shani AB (Rami., Coghlan D. Action research in business and management: A reflective review. Action Res. 2019. doi:10.1177/1476750319852147

59. Susman GI. Action Research: A Sociotechnical Systems Perspective. (Morgan. EG, ed.). London: Sage Publications; 1983.

60. Lewin K. Action Research and Minority Problems. J Soc Issues. 1946;2(4):34-46. doi:https://doi.org/10.1111/j.1540-4560.1946.tb02295.x

61. McAteer M. Action Research in Education. London: Sage; 2013.

62. Frisendal T. Graph Data Modeling for NoSQL and SQL - Visualize Structure and Meaning. First. Basking Ridge, New Jersey: Technics Publications; 2016.

63. Johng H, Kim D, Hill T, Chung L. Using blockchain to enhance the trustworthiness of business processes: A goal-oriented approach. In: Proceedings - 2018 IEEE International Conference on Services Computing, SCC 2018 - Part of the 2018 IEEE World Congress on Services. IEEE; 2018:249-252. doi:10.1109/SCC.2018.00041

64. Korpela K, Hallikas J, Dahlberg T. Digital Supply Chain Transformation toward Blockchain Integration Kari. In: 50th Hawaii International Conference on System Sciences. ; 2017.

65. Avison D, Lau F, Myers M, Nielsen PA. Action research. Assoc Comput Mach. 1999;42(1):94-97. doi:https://doi.org/10.1145/291469.291479

66. Davison RM, Martinsons MG, Kock N. Principles of canonical action research. Inf Syst J. 2004;14(1):65-86. doi:10.1111/j.1365-2575.2004.00162.x

67. Brydon-Miller M, Greenwood D, Maguire P. Why Action Research? Action Res. 2003;1(1):9-28. doi:10.1177/14767503030011002