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The Value of Digital Inventory Governance for Spare Parts: Case Study from the Norwegian Oil and Gas Industry

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Abstracts: This research explores the governance of digital inventory platforms for spare parts in the Norwegian oil and gas industry, focusing on both centralized and decentralized configurations. Research methods, including an extensive literature review, comprehensive industry interaction, and detailed interviews with additive manufacturing experts, highlight key characteristics of digital inventory platforms and identify the influencing factors toward optimal formation. Additionally, it evaluates the risk implications of these configurations, demonstrating how centralized models ensure data integrity and compliance to industry standards, while decentralized models potentially facilitate innovation and increased responsiveness within the value chain. Effective governance of these platforms can not only boost operational efficiency but also strengthen the industry's resilience amid a dynamic and turbulent global business environment.

Keywords: Digital inventory, Governance of digital inventory platforms, Additive manufacturing, Spare parts, Oil and gas industry, Risk management.

1. Introduction

The global business environment has been changing significantly due to rapid digitalization and technological advancements across both public and private sectors, with the main purpose of enhancing the performance of operating assets and the quality of services. In the modern industrial era, organizations need an integrated strategic approach with modern decision-making tools to actively evaluate their business model elements, ensure alignment with stakeholder demands, and balance their core competencies and resources to meet contextual socioeconomic requirements. These measures are essential for sustaining growth and profitability while ensuring adaptability and resilience. (Liyanage and Uusitalo 2017)

Among different industrial sectors, the oil and gas (O&G) industry is facing severe challenges, uniquely compounded by its critical role in the global energy landscape and the multifaceted performance demands of new value chains. Furthermore, according to a recent research by (Haouel and Nemeslaki 2023), the key challenges that the O&G industry faces are:

- "The increasing transition to clean, green energy.
- Technological innovation disrupting nearly all industries, resulting in new business models and heightened market competition."
- And global disruptions such as the COVID-19 outbreak and geopolitical challenges like the Suez Canal closure have significantly impacted supply and demand dynamics in the industry.

A technological innovation driven by Additive manufacturing (AM) technology is the emergence of platforms storing product design files, which are commonly called in the industry as, Digital inventories (DIs).

AM is an advanced production method that utilizes computer-aided design (CAD) files to create physical components often layer by layer, and it has evolved significantly from its earlier role in prototyping to producing end-use parts. In

contrast to conventional subtractive manufacturing, AM uses less material, making it renowned for its operational efficiency.

These CAD files—commonly referred to as digital parts or spare parts— that are essential for physical part production via AM machines, are typically owned by Original Equipment Manufacturers (OEMs) in the form of Intellectual property (IP). Selling these spare parts has increasingly become a major part of many OEMs' business model.

Now, with the transformational concept of storing and transferring digital parts electronically and produced on demand, close to end-users, rather than relying on traditional multi-echelon distribution networks, the discussion of digital inventory governance becomes pivotal in the new value chain. This is because OEMs who intend to diversify their revenue stream by actively participating in AM industrial ecosystem, either through selling or licensing the digital spare parts, they have to share the critical design information of the parts with mainly two key entities. First, a digital platform to ensure secure procurement of digital parts between a range of stakeholders and actors, and second, the AM suppliers, who own the AM machines, to produce and deliver the parts to the end users. Clearly this new value chain setting introduces unique possible threats to OEMs' business models and unique challenges for the industry.

Despite significant investments, large-scale adoption of digital inventory platforms in the Norwegian O&G industry remains limited, highlighting a critical governance gap. This study investigates stakeholder perspectives to identify key enablers and barriers, offering industry-specific insights for optimizing digital inventory adoption within a complex supply chain environment.

In addition, (Tubis and Rohman 2023) in their study of intelligent warehouses, identified a critical research gap in understanding the risk implications of digital warehouses to contribute to the concept maturity.

Therefore, the objective of this article is to shed light on the novel concept of digital inventory governance for spare parts and its value creation within the context of the Norwegian O&G industry.

2. Methodology

This study employs a pragmatic and exploratory methodology, integrating two key components: first, a literature review to establish theoretical and technical foundations while identifying research gaps; and second, semi-structured interviews with 15 key stakeholders—including an OEM, AM suppliers, operators, and service providers. Interview insights were thematically categorized (e.g., operational efficiency, risk mitigation, governance models) and cross-validated against literature findings to provide a comprehensive understanding of the value of digital inventory and the potential benefits of its centralized and decentralized formations.

2.1 *Literature review approach*

The literature review provides the foundational context for understanding digital inventory governance. Building on the extensive review conducted for the master's thesis research, (Farshchi and Raza 2024) which incorporated over 90 credible sources including scholarly articles, industry reports, and online publications, this study integrates updated materials to refine and expand the analysis. A narrative and thematic review approach was adopted, allowing flexibility to focus on relevance rather than procedural rigidity. Searches were conducted in databases such as Google Scholar and ScienceDirect using terms like "digital inventory," "spare parts," "digital platform governance," "additive manufacturing in oil and gas," and "digital transformation in supply chains." This approach identified key trends and research gaps.

2.2 *Expert interviews*

To complement the literature review, semi-structured interviews were conducted with purposive sampling with 15 AM experts from the Norwegian oil and gas industry to clearly challenge the status que understanding of DIs to discover hidden challenges and productive ideas with respect to the article objective. Interviews, informed by a rigorous literature review and expert collaboration, included stakeholders such as an OEM, three operators, three AM suppliers,

two research centres, and six service providers. This diverse participation contributes to the comprehensiveness and reliability of the study's findings.

2.3 *Data analysis and validation*

Interview data were analyzed using a combination of manual coding and digital tools. Key themes were first documented manually to allow an organic, immersive engagement with the material. The data were then transcribed and categorized in Microsoft Excel for systematic organization and further analyzed using Python to identify patterns and interrelations quantitatively. This combination of tools ensured a balance between intuitive engagement and computational rigor. The analysis was guided by an inductive approach, allowing themes to emerge naturally rather than imposing predefined frameworks.

For validation, a triangulation approach was implemented by cross-verifying findings from the literature review, interview analysis, and reflective insights. Three industry experts and two academics validated the findings, reinforcing their relevance and credibility within the Norwegian AM ecosystem.

3. Theoretical Background

3.1 *Supply chain and spare parts*

Supply chain disruptions often arise from uncertainties on both supply and demand sides, while exacerbated by factors like labour strikes and pandemics, leading to multifaceted risks. (Ulutan et al. 2022) In essence, the necessity of the inventory concept relies simply on the fact that the demand facing an organization may not always be equal to its production capacity to ensure proper service level and reliable sales. (Muckstadt and Sapra 2010)

For example, with regards to spare parts, Knofius, Van Der Heijden, and Zijm (2019) noted that spare parts management is becoming increasingly complicated due to considerable increases in three influencing factors: the distribution of assets located far from inventories, the variety of spare parts types, and the complexity of these parts, which consequently can lead to higher prices.

According to Ratnayake (2019), “the main objective of spare part evaluation and control is to make sure that the right quality spare parts are available at the right time in the right place at an optimal cost.”

Therefore, balancing spare parts availability and inventory holding costs is critical for effective inventory management. Financial control aims to minimize the associated costs and maximize working capital but risks operational disruptions and increased HSE (Health, Safety, Environment) threats. On the contrary, operational control aims to ensure equipment availability and reduce HSE risks but may potentially lead to overinvestment, different obsolescence types, and high holding costs, underscoring the need for balanced governance to achieve both cost efficiency and reliability.

3.2 *Digital inventory*

In essence, the digital inventory is a data repository to store and make the digital spare parts, i.e. the production design files available for OEMs to sell certain parts to end users so that they can print the parts on demand and on site. However, OEMs may lack interest or the capability—primarily due to their business models or cybersecurity constraints—to establish direct connections between their local digital inventory and various customers, whether loyal or new. As a result, they often favor an intermediary entity, such as a digital platform, to ensure security and reliability of procurement of the digital spare parts.

The study by (Ballardini, Flores Ituarte, and Pei 2018) identified a digitization trend in existing inventories aimed at delivering flexible and scalable spare parts services through e-commerce (digital) platforms. The researchers also observed that several OEMs have begun formulating strategies to advance the development of these digital inventories.

The optimal value creation of digital inventory lies in facilitating seamless on-demand manufacturing through AM, which, in the future, could also integrate other advanced manufacturing technologies such as CNC machining or robotics, enhancing flexibility and efficiency in production.

Promotion of on-demand manufacturing approach, which is a responsive production model that starts upon receiving customer order, can facilitate eliminating the need for large

inventory stockpiling and increase rapid machinery reconfiguration, supports innovative designs and increase efficiency and responsiveness against cyclic demands, market uncertainties and capacity shortages. (Westkämpfer 1997)

On demand manufacturing via AM can effectively enable a scalable just-in-time approach within the industry that allows to decrease inventory levels without reducing spare parts availability, a huge possibility to cut lead times from months to weeks, and promising local production and regional value creation which indeed can contribute to decrease dependency on foreign suppliers and thus, reducing associated financial and operational risks for asset operators. (Meier 2020)

3.3 *Governance for digital platforms*

Digital platforms are technology-enabled business models that create value by facilitating multifaceted interactions among diverse parties, typically through Business to Business (B2B) or Business to Consumer (B2C) connections, i.e. performing two critical roles of "acting as a technological foundation and as a market intermediary." (Pauli, Fielt, and Matzner 2021)

The defining attributes of industrial digital platforms are their multi-sided nature, enabling interactions among multiple stakeholders; network effects, where value increases with participation; interconnectivity, allowing seamless system and stakeholder integration; and data-driven insights, which optimize decision-making and operations.

Moreover, a key aspect of digital platforms is their governance model which essentially derives from their very core business model elements and the applied control mechanisms. Research on the governance of digital platforms is inherently difficult due to their decentralized nature, deep integration with a spectrum of stakeholders with different interests, markets, new technologies, and their rapid expansion into various industries, creating complex sociotechnical structures. (De Reuver, Sørensen, and Basole 2018)

According to Chen, Richter, and Patel (2021), a digital platform that effectively manages local information and aligns with individual incentives can achieve a high participation rate among suppliers and customers. Leveraging the network effect inherent in digital platforms, such a system can foster and sustain a dynamic and robust business ecosystem that addresses participants' interests and needs while delivering efficient and reliable outcomes.

Subsequently, a key element of digital platform governance is the level of decentralization that vary from fully decentralized to fully centralized digital platforms. According to Chen, Richter, and Patel (2021), the level of decentralization is of paramount importance. The level of decentralization also depends on the platform's operational and financial domain, including the targeted industrial sector and then the type of financial relationships, whether Business to Business B2B or B2C. (Chen, Richter, and Patel 2021)

Drawing insights from (Chen, Richter, and Patel 2021), centralized governance can provide streamlined management, data consolidation, and improved centralized decision making but comes with the inherent risk of concentrating vulnerabilities. Security breaches in centralized platforms can significantly impact market position, reputation, and even business survival, as sensitive data often defines competitive advantage. Additionally, heavy governance mechanisms may put limit on co-value creation within the ecosystem and thus decrease the platform participants' flexibility to making adaptation to market trends.

In contrast, decentralized governance can empower stakeholders through enhanced communication and collaboration, fostering greater engagement, co-value creation, and innovative solutions. While centralized platforms ensure stability and trust in immature markets, decentralized platforms can excel in mature industries by fostering flexibility, innovation, and stakeholder-driven solutions. Thus, balancing power dynamics and mitigating security risks are essential for building trust and ensuring effective governance in digital ecosystems. (Chen, Richter, and Patel 2021)

3.4 ***The concept of digital inventory platform governance***

To the best of the authors' knowledge, the digital inventory governance characteristics and its impacts on spare parts remain underexplored. This gap motivates further investigation into the identity, attributes, and impacts of digital inventory governance, particularly within the context of the Norwegian O&G industry.

Digital inventory platforms can enhance supply chain visibility by centralizing spare parts' attributes, procurement details, and CAD files, streamlining access to technical and non-technical information. The creation of this information integration via DI platforms depends on their governance structure which subsequently address participation incentives for diverse organizations and businesses (B2B), and facilitating comprehensive and interconnected information management system that will have significant impacts on shaping the new value chain in the industry. (Ballardini, Flores Ituarte, and Pei 2018)

Within the context of digital inventories, the main relevant stakeholders in this network are OEMs, DI platform owners, operators (end-users) and the AM suppliers. While the number of stakeholders in a digital supply network is clearly far more than these, however, within the scope of this article, the focus is on roles of these stakeholders only.

Where a centralized digital inventory functions like a central library showcasing numerous items from different authors, a decentralized configuration could serve as a host or hub of independent OEM-owned digital inventories, creating a digital network connecting them with AM suppliers and asset operators.

In a decentralized setup, the relationships among stakeholders can adapt to their mutual needs, with the governance of the digital inventory platform focused on providing a secure and reliable framework for transactions, not necessarily owning any digital spare parts.

An illustrative and simplified representation of the governance for such platforms could be as follows:

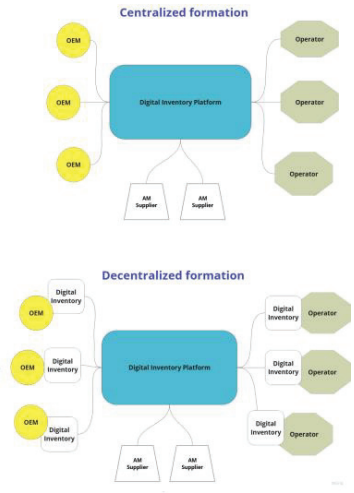

Figure.1. Simplified representation of centralized and decentralized digital inventory platforms (Farshchi and Raza 2024)

4. Findings and Discussion

4.1 *Value creation of DIs for spare parts*

With regards to operational domain of spare parts control, participants identified several challenges, such as long lead times, which significantly affect asset production availability, and the huge number of spare parts distributed across multiple warehouses owned by different operators across Norway's coasts. Many of these parts are increasingly becoming obsolete due to rapid technological advancements and evolving industry standards. Additionally, participants noted poor documentation practices, making it challenging to track and evaluate spare parts effectively.

On the other hand, regarding the financial perspective of spare parts control, participants emphasized the high costs associated with maintaining inventories, including storage and upkeep expenses, which one operator estimated to be about 25% of their total inventory value annually. Emergency deliveries from suppliers also incur significantly high costs, especially for critical operational parts. Furthermore, participants pointed out that there is a huge opportunity of sorting and recycling obsolete parts in inventories of assets nearing decommissioning phase, to both contribute to free up physical inventories, establishing better database for old parts, and contribute to a relevant concept of circular economy.

Participants recognized DI platforms as transformative digital tools for addressing current interconnected operational and financial challenges. Key strategic advantages include driving the commercialization of digital spare parts, empowering the AM market, and facilitating large-scale adoption of on-demand manufacturing. Additionally, DI platforms have the potential to serve as knowledge-sharing interfaces, cultivating an AM-based culture and enabling more risk-informed decision-making across the ecosystem. These platforms can also enhance operational coordination and foster direct collaboration between key stakeholders, including OEMs, AM suppliers, and operators.

For example, it was also mentioned that Equinor, leading Norwegian energy company, planned to digitize their inventory and reduce their physical inventories by 50% in ten years equating to reduction of many tonnes of equipment and promising massive cost efficiency while ensuring part availability via DIs and AM technology capabilities.

These findings suggest that DIs can potentially have significant impact on establishing a seamless synergy between operational and financial domains of spare parts management. By reducing lead times, minimizing part obsolescence, and improving documentation, critical operational bottlenecks will be addressed. Additionally, it was noted that with the emergence of DIs, a low probability high consequence possibility of fake components will be eliminated based on DI platform inherent interconnectivity and data-driven insights.

Moreover, they can simultaneously lower physical inventory maintenance costs, mitigate financial risks associated with emergency deliveries, and reduce assets' downtime. Consequently, these capabilities of DIs can position them as a strategic enabler for enhanced efficiency of spare parts and contributing to the resilience of the Norwegian O&G industry.

4.2 *Governance*

The comparison between centralized and decentralized DIs formations reveals contrasting benefits and challenges across key dimensions such as value creation, risk implications, and stakeholder participation, which the participants' preference is depicted as follows:

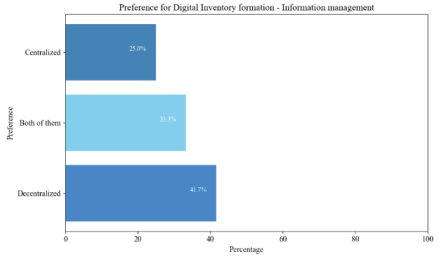

Figure.2. Comparison between centralized and decentralized DIs – with regards to information management (Farshchi and Raza 2024)

While participants recognized the potential benefits of both formations, decentralized models were generally preferred for their flexibility and stakeholder control. A major concern raised by participants was the risk concentration inherent in centralized platforms, echoing the points discussed in Section 3.3. Participants expressed OEMs' concerns about the escalating risks of distributing their digital spare parts across multiple centralized platforms. Decentralized platforms were favored by OEMs for their ability to maintain control over their digital spare parts, including better IP protection and ease of revision updates. Conversely, managing revisions across multiple centralized platforms could require significant resources, resulting in inefficiencies and duplication.

Operators expressed a preference for centralized platforms due to their consolidated data management capabilities and alignment with standardization processes facilitated by organizations like DNV for standards such as DNV-ST-B203. Centralized platforms were perceived as a "single source of truth" for digital spare parts, offering economies of scale that gradually reduce standardization costs. Additionally, early-stage adoption of centralized platforms was viewed as beneficial for OEMs with less developed digital infrastructure, as these platforms provide structured support and reduce the need for advanced systems.

While centralized platforms may excel in stability and scalability, participants noted that they may limit participation from smaller

businesses and service providers, which are critical for fostering innovation and product customization. Decentralized platforms, by contrast, can handle and promote broader inclusion, local decision-making, and effective stakeholder collaboration, creating a dynamic ecosystem where innovation can thrive.

Ultimately both formations can offer distinct strengths, and their optimal use depends on stakeholder needs, operational flexibility, and scalability. Therefore, these findings suggest that in order to achieve effective platform governance, reaching and maintaining a balance over these key influencing factors is necessary:

- Risk Concentration
- Effective IP Control
- Platform compatibility for seamless communication with standardization bodies like DNV
- Flexibility to facilitate innovation-driven solutions
- Infrastructure readiness for both OEMs and operators

5. Conclusion

Digital inventory governance has the potential to make a paradigm shift in spare parts control by enhancing operational efficiency, enabling reliable customization, and improving predictability and resilience. While centralized platforms can streamline operations but pose risks due to concentration, decentralized platforms foster better flexibility and co-value creation. Proactive strategies that balance these strengths can empower the Norwegian O&G sector to adapt to evolving market demands and seize emerging opportunities. (Wirtz 2021)

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