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Review

Industrial Internet of Things (IIoT) and Other Industry 4.0 Technologies in Spare Parts Warehousing in the Oil and Gas Industry: A Systematic Literature Review

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Abstract: *Background:* Spare parts warehousing in the oil and gas industry is essential for offshore production. With the introduction of Industry 4.0 and its subsequent technological tools, new functions are enabled in industrial logistics activities. Efficiency, visibility, optimization, and productivity are often mentioned as benefits of successful Industry 4.0 technology implementation in logistics activities. In this paper, the implementation of Industry 4.0 technologies such as the Industrial Internet of Things (IIoT) in spare parts warehousing in the oil and gas industry is studied. *Method:* 133 peer-reviewed journal publications indexed in Scopus and Web of Science are analyzed in a systematic literature review. The review is structured as frequency and content analysis. *Aim:* As there is limited research on this specific topic, the aim is for this paper to be a theoretical foundation that assists the industry with future solutions. *Results:* The list of benefits of implementation gathered from the literature is comprehensive. However, the list of challenges is particularly pertinent to the oil and gas industry and indicates a strong inclination towards limited and controlled implementation of some technologies. The safety demands of the industry mean there are many limitations to implementation currently. *Conclusions:* This paper reflects on the results, identifies research gaps, and gives proposals for future research.

Keywords: industrial internet of things (IIoT); industry 4.0; oil and gas industry; warehouse management; spare parts warehousing

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1. Introduction

Industry 4.0 technologies are contributing to the transformation of operations and activities in several industries [1]. In 2019, Koh et al. [2] predicted that Industry 4.0 technologies would lead to extensive innovation regarding new products, materials, manufacturing processes, and activities. Five years later, there are examples of implementation and research relating Industry 4.0 technologies to the food processing industry [3], the pharmaceutical industry [4], the manufacturing industry [5], and the retail industry [6], among others. Industry 4.0 and its potential for innovation is undeniable at this point [7].

It is an aim for warehousing to benefit from Industry 4.0 technologies in various industries [8]. One of the integral concepts of Industry 4.0 is interconnectivity—the ability of systems and components to communicate with each other and exchange relevant information without human commissioning and interference. Managers within supply chain management and warehousing are eager for their operations to have increased visibility and efficiency through such interconnectivity enabled by Industry 4.0 [9]. The smartness of Industry 4.0 technologies enables warehouses to increase service efficiency, productivity, and visibility of items across the supply chain—concepts that are of high interest to industries [10].

Research on Industry 4.0 technologies in the oil and gas industry's logistics activities is very limited. A quick search on Scopus in March 2023 yielded only four peer-reviewed journal articles with "Industry 4.0", "oil", and "gas" in the article title. Similarly, a search for articles with "IIoT", "oil", and "gas" in the title only yielded three results, all of which were conference articles without guaranteed peer review. Interestingly, none of the few articles that appear in these searches are centered on warehousing or supply chain management but are more generic in their approach. It appears that Industry 4.0 technologies in warehousing in the oil and gas industry now is a niche field requiring fundamental research groundwork.

IIoT can be considered one of the fundamental technologies of Industry 4.0. IIoT is the practice of consistently obtaining information from items through sensors, and then passing on this information to data centers in the cloud, which updates related parameters by a closed-loop system [11]. This enables organizations, particularly in manufacturing fields, to create new ways of operating as well as extend their current operating methods. Examples include using IIoT for predictive maintenance, big data analysis, and machine health analysis [12]. The interconnectivity at the very core of Industry 4.0 in industrial practice is largely enabled by the Industrial Internet of Things.

The oil and gas industry is of major importance to industry and society. The value generated by the industry supplies economies with financial value, societies with growth, and people with jobs and income [13]. However, the oil and gas industry was considered behind other industries in technological advancement just a few years ago [14]. Now there is evidence that industry starting to slowly progress in technology implementation in developed countries [15]. This is due to improved technology familiarity as well as competition: both contribute to driving technology usage and implementation forward.

The oil and gas industry, although of great importance to society, is currently under scrutiny for high carbon emissions and negative environmental impacts [16]. Several global oil and gas production companies have set ambitious goals of decreasing their emissions and increasing their investments in renewable energy sources within limited timeframes [17–19]. It is believed that the implementation of digital technologies, IIoT among them, can help energy production companies in the transition towards net zero [20].

Decreasing emissions and achieving net zero in the oil and gas industry is no simple task. The commodities that constitute most of the production and income sources cannot be produced and utilized without emissions. As net-zero emissions mean no additional levels of greenhouse gases through human activity, the solution would also have to involve carbon capture and storage (CCS) and emission decreases in other activities relating to energy production. One such activity that holds potential for emission reduction is warehousing. The oil and gas industry is dependent on spare parts inventories to ensure access to critical components in case of malfunction or maintenance of equipment offshore [21]. This often results in large warehouse facilities filled with spare parts by a just-in-case policy, which can cost companies vast sums yearly [22]. Ordering spare parts from various global manufacturers, storing them in the warehouse, and potentially discarding them if not used all contribute to redundant emissions.

This redundancy can be reduced or eliminated through increased optimization, which can be achieved with Industry 4.0 technologies implementation. Technologies like IIoT could assist by enabling predictive maintenance [23], which allows for a just-in-time policy for spare parts rather than just in case. IIoT could also be used in the warehouse facility for sorting parts, decreasing time expenditure and human labor [24]. Theoretical possibilities of IIoT and other Industry 4.0 technologies in some industries are present in the literature. To the authors' knowledge, there exists no research consolidating the relevant literature for the purpose of spare parts warehousing in the oil and gas industry.

In this paper, a systematic literature review (SLR) is conducted to establish a theoretical foundation for future practical implementation in the field. The SLR is driven by the following research questions (RQs):

RQ1: How can spare parts warehousing in the oil and gas industry benefit from the implementation of IIoT and other relevant Industry 4.0 technologies?

RQ2: What difficulties or challenges can an oil and gas production company face in implementing IIoT and other relevant Industry 4.0 technologies?

RQ3: What research gaps exist today in the field of Industry 4.0 technologies in the oil and gas spare parts field?

This study is divided into parts. First, the methodology of the study is outlined. Then an analysis of the literature is conducted. Thereafter, an elaboration on the practical implications of the findings follows. Lastly, reflections and suggestions for future study conclude this paper.

2. Methodology

An SLR is a research method that examines the relevant literature in relation to one or several specified research questions [25]. SLR is chosen for this research as it is an organized and meticulous process for gaining an overview of the relevant literature. For areas in which research is not yet mature, SLRs provide decent groundwork for other researchers to conduct future research.

The SLR is conducted through a process, illustrated in detail in Figures 1 and 2.

The electronic bibliography databases Scopus and Web of Science are used to find relevant research articles, due to their extensive libraries and accessibility. The keyword search is the same in both databases. The keyword is searched for in article titles, abstracts, and keywords in Scopus, and abstracts on WoS. The following inclusion criteria are implemented in the search:

- Language of publication (English only).
- Document type of publication (peer-reviewed journal articles only).
- Publication date of publication (up to and including the date 16 May 2023).
- Subject areas in Scopus: engineering; computer science; business, management, and accounting; decision sciences; mathematics; materials science; physics and astronomy; social sciences; environmental science; chemical engineering; energy; biochemistry, genetics, and molecular biology; chemistry; neuroscience; economics, econometrics, and finance; multidisciplinary; and psychology.
- Subject areas on WoS: engineering electrical electronic; management; computer science interdisciplinary applications; engineering multidisciplinary; computer science information systems; operations research management science; engineering industrial; engineering manufacturing; computer science artificial intelligence; telecommunications; instruments instrumentation; materials science multidisciplinary; physics applied; chemistry multidisciplinary; computer science software engineering; environmental sciences; automation control systems; chemistry analytical; computer science hardware architecture; energy fuels; environmental studies; green sustainable science technology; information science library science; neurosciences; robotics; business; computer science cybernetics; economics; engineering chemical; engineering mechanical; mathematics interdisciplinary applications; social sciences interdisciplinary; and transportation.
- The abstracts of each paper in the search result were read thoroughly to determine its relevance. The exclusion threshold was high. All abstracts that indicated the publication would mention, analyze, consider, or research benefits or challenges of the implementation of Industry 4.0 technologies were included: language was the strongest indicator for inclusion. One paper was excluded from the Scopus search because its content and analysis only related to the medical field.
- Publications not available online were excluded. Some titles appeared in the database searches, but the publication texts in their entirety were unavailable. Searches for these publication titles were then made in online search engines such as Google, to attempt to find the texts outside the databases. When these attempts were unsuccessful (which they were in every case the publications were unavailable directly from the database), the papers were removed from the final list of publications.
- Funding sources for the publications were not examined.

- Methodologies of the included publications were not qualifying or disqualifying for inclusion.

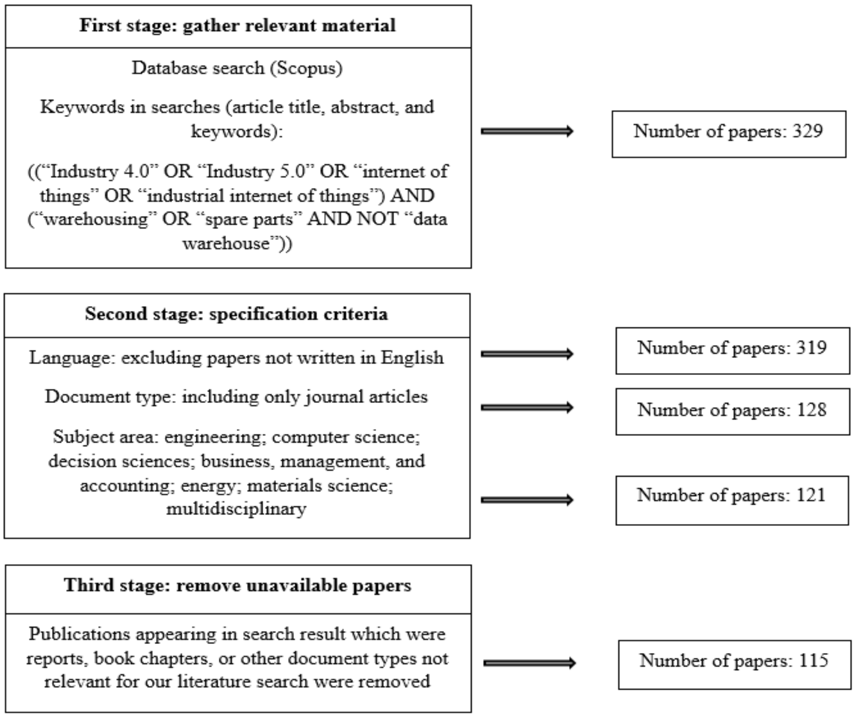

Figure 1. SLR process for the literature search on Scopus.

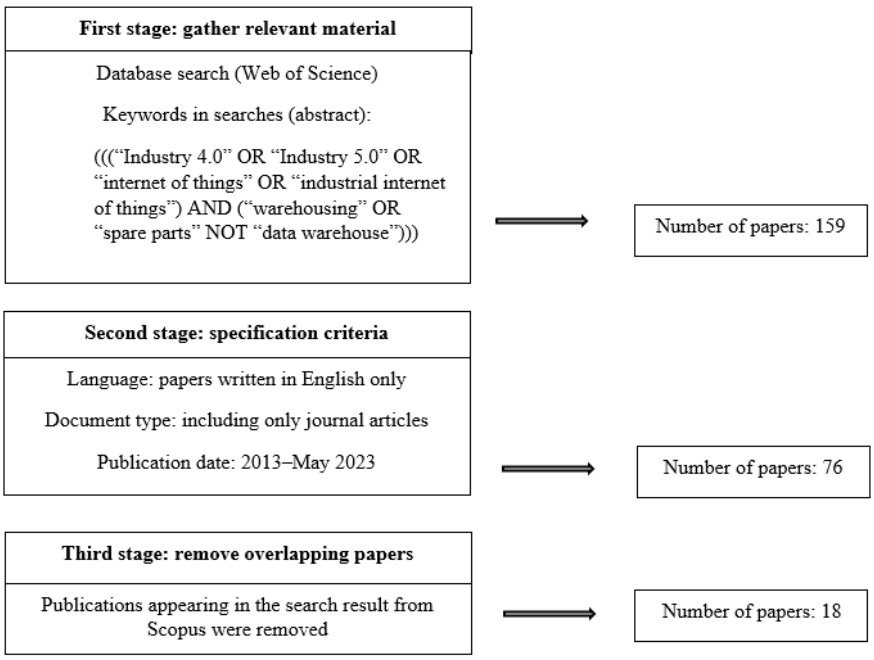

Figure 2. SLR process for the literature search on Web of Science.

The search in Scopus resulted in 329 papers, while the search on WoS resulted in 76 papers. A thorough examination of the results was conducted to ensure that only papers that could be viewed in their entirety and sourced back to named authors were selected. Additionally, overlapping results that appeared in both database searches were noted and kept in the Scopus search result only. The result is a paper amount of 115 in Scopus and 18 in Web of Science—a total amount of 133.

The 133 papers are multidisciplinary. The papers' case studies and analyses are from various industries such as aviation and automotive. The immediate takeaway is that there is practically no research on IIoT and related Industry 4.0 technologies in spare parts warehousing in the oil and gas industry. This literature review will be work that draws from other fields to establish learnings for the oil and gas industry. It can be considered an important initial step for the oil and gas industry to use multidisciplinary research in technology implementation in logistics activities.

3. Literature Analysis

The literature analysis is divided into two: a frequency analysis and a content analysis. An overview of the literature is established and systemized to withdraw relevant information and learnings for the oil and gas industry. The frequency analysis considers publication year and methodology, while the content analysis considers aspects of technology implementation.

3.1. Frequency Analysis

The frequency of papers published on the topic is illustrated in Figure 3. No lower limit on publication date is set and the one paper published in 2013 is the first one matching the search criteria. The paper published in 2013 is on the topic of the Internet of Things and analyzes how IoT in combination with cloud computing could be key to handling large amounts of data in the future [26]. The next publication is from 2015 and is highly relevant as it considers IoT in a warehouse setting [27]. Although IoT and IIoT are considered key technological components of the fourth industrial revolution, the term "Industry 4.0" was not used in any publication in the search until 2016. Thereafter, the number of publications increases steadily until 2019, from which point onwards there is a greater growth until 2022. Although the publication amount in 2023 is on the same level as it was before the sharp increase in 2019, this number can be expected to be higher by the end of the year considering the publication trends.

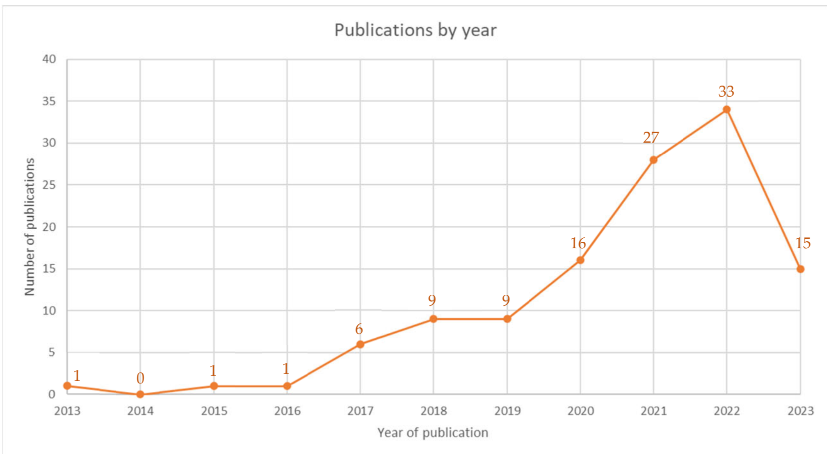

Figure 3. Frequency analysis by year of publication.

3.2. Publisher-Wise Analysis

Paper distribution by journal is presented in Table 1. Journals centered on production and manufacturing have produced the largest volume of publications on the topic of IoT and IIoT in warehousing and spare parts management. Almost 100 journals have published one or two papers each on the topic, and these journals' fields include cognitive science, instrumentation, and transportation. Approximately four out of five papers (80.7%) are published in journals with only one or two papers on the topic. The applicability of IoT and IIoT in the context of warehousing and spare parts is significant for many industries.

Table 1. Number of articles by publication channel.

Journal Name	Number of Articles
Applied Sciences Switzerland	7
International Journal of Production Research	6
Sustainability Switzerland, Journal of Science and Technology Policy Management, Sensors and Materials	4
Computers and Industrial Engineering, International Journal of Advanced Manufacturing Technology, Energies, IEEE Internet of Things Journal, Logforum	3
Advanced Engineering Informatics, Computational Intelligence and Neuroscience, Computers in Industry, IEEE Access, Industrial Management and Data Systems, Mm Science Journal, Scientific Programming, Sensors	2
Others	1

3.3. Study Nature Analysis

The nature of this study is such that it covers many areas of study. "IIoT and technologies in warehousing and logistics" is a broad topic, and studies into it can cover areas like engineering, sociology, computer science, and many more. To gain an overview of the encompassing topics for all articles, a distribution percentage from the results is derived. Some of the articles fall under several of these study areas, and this is taken into consideration in the overview. The distribution is shown in Figure 4.

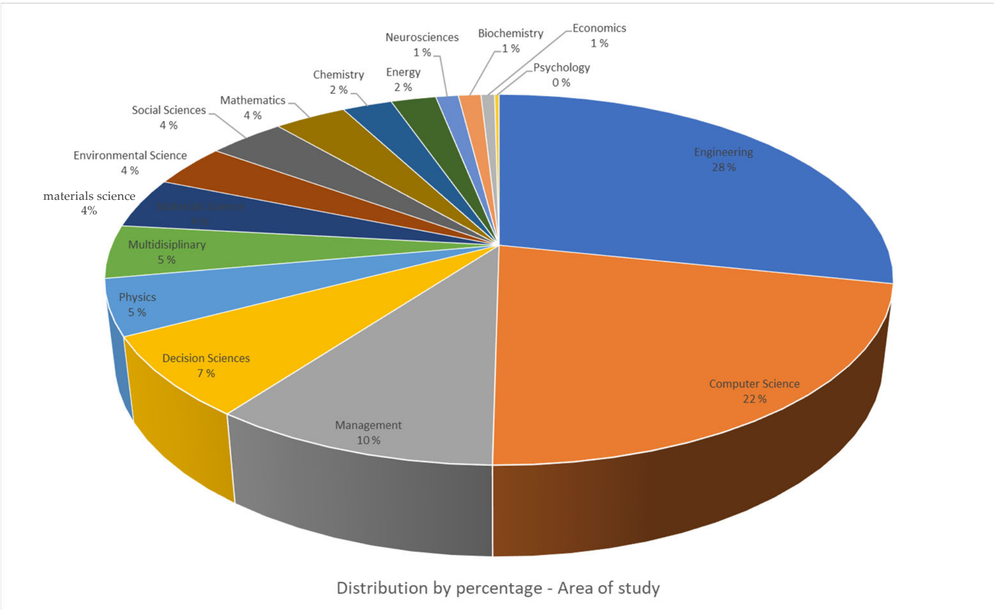

Figure 4. Distribution by percentage of the study areas of the articles from the search. Data gathered from Scopus.

The distribution shows that half of the papers fall into one of two categories: engineering and computer science. Approximately one tenth of the papers can be sorted into management and business. The remaining study areas encompass less than 10% of each of the articles in the search result. This shows that a significant number of the search results have a technical focus. Most of the articles are centered around the specifications of the relevant technologies to meet the requirements of the described systems and successfully answer the posed research questions.

4. Content Analysis

4.1. Benefits of Implementation of IoT and IIoT and Other Industry 4.0 Technologies—A Descriptive Analysis

The traceability feature of IoT enables benefits such as reliability, fast response time, efficiency, and accuracy [28]. In maintenance work, IoT or IIoT has been used to feed data to digital twins where whole systems can be monitored [29]. Research has been conducted into using IoT in spare parts intralogistics in aviation, where it can be used to facilitate traceability and visibility through data analysis [30]. In farming, IoT is used to monitor the rice paddy environment and predict the plant's water level, saving wasted water and energy in the process [31]. Across industries, Tannady et al. [32] state that IoT's uses and benefits within logistics are limitless.

According to Jarašūniene et al. [33], IoT is the key technology in processing data in warehouse management with high efficiency. IoT's use in warehouse management is stated to encompass monitoring, tracing goods, demand trend forecasting, inventory management, and other real-time warehouse operations. The results of successful IoT implementation in these activities are given to be improved financial performance, labor productivity, and customer satisfaction. Improvement in decision making through Industry 4.0 technologies has benefits along an industry's value chain, including external suppliers and outsourcers [34]. In healthcare, IoT in combination with blockchain and cloud computing secures the storing of health records, whose benefits are transparency and decentralization [35]. In engineering, IoT is also used in combination with blockchain to maintain the benefits of IoT while simultaneously avoiding data leaking—which speaks to cyber security, an important aspect in today's Industry 4.0 technology usage [36].

Talpur et al. [37] explain how IoT traceability systems normally use Radio Frequency Identification (RFID), Wireless Sensor Network, and Near Field Communication. It is explained how product traceability first became a necessity in food and pharmaceutics. Experience from these industries served as an example of how product quality is dependent on quality and precision in previous steps, and that the final product's quality is dependent on optimal traceability along the whole supply chain, including external collaborators and vendors.

Pasparakis et al. [38] expand on the importance of ensuring human involvement and human–technology collaboration to ensure a seamless transition from Industry 4.0 to Industry 5.0. This is to allow for flexibility and customization, which is easier to achieve when there is a certain level of human involvement. The benefit of Industry 4.0 technologies and humans together in a warehouse is the automation of time-consuming tasks and "outside-the-box" problem solving by humans. An indoor positioning system (IPS) is highly useful in combination with IIoT and would further assist humans in the warehouse with time expenditure [39]. Human factors in synchronization with technology are considered essential for operational success, particularly in warehouse order picking [40].

In spare parts inventories, IoT provides a unique opportunity for the prediction of future maintenance needs [41]. Here, IoT can give predictions on the state of installations or assets, which in turn can drive dynamic decision models that conduct maintenance and refilling actions in an efficient manner while reducing risk. With optimal planning for this type of system, maintenance-dependent industries can develop functioning frameworks for ideal IoT data utilization. In a warehouse setting, order picking is the costliest of all activities, partly due to the localization of relevant goods [42]. Order picking 4.0 entails using the technologies and interconnectivity principle of Industry 4.0, of which IoT is an important part. Appropriate utilization and implementation of technologies enable operational planning of warehouses, which is necessary for them to remain resilient and competitive in an increasingly complex industrial world.

Abdul Rehman et al. [43] state the benefits of IoT in logistics activities as facilitation of data exchange, communication between elements, and remote monitoring. Sahara et al. [44] explain that enhanced control, improved performance in the supply chain, and increased customer satisfaction are among the main benefits of IoT. Lastra et al. [45] claim that

Industry 4.0 technologies add value to the entire product life cycle. Al Hanbali et al. [46] outline that technology such as IoT, with the ability to sense and communicate, leads to measurement accuracy and cost reduction in logistics activities related to spare parts supply.

Aside from the general benefits of IoT and related technologies in various industries, it is wise to examine the benefits related to spare parts management in particular. Table 2 shows the benefits of IoT and other Industry 4.0 technologies as stated in the literature related specifically to spare parts management.

Table 2. Benefits of IoT and other Industry 4.0 technologies in spare parts management, as identified in peer-reviewed literature.

Industry 4.0 Technology	Benefits	Publication
Artificial intelligence (AI), digital twin (DT), IoT, smart manufacturing	Reduced costs; reduced negative environmental impacts of machine failure; reduced maintenance costs; reduced downtime; improved working life of assets; increased production; increased company's profit; ensured required quality of products; improved operational safety; improved overall sustainability	Rojek et al. [29]
IoT, Cyber–physical system (CPS), RFID	Improved resource coordination; improved utilization; improved prediction; improved efficiency in management, execution, decision making, and system levels; improved collection of real-time spatial–temporal resource information; improved traceability and visibility of capacity and availability; improved configurability of workflows; flexible front-end operations; enhanced timeliness in cooperation among participants in business processes	Chen et al. [30]
Machine learning (ML)	Reduction in error of time-to-failure predictions; improved response time through data dimensionality reduction	Elmdoost-gashti et al. [47]
IoT	Reduced costs; increased reliability; increased prediction accuracy; improved opportunities for driving decision models for maintenance and replenishment actions	Shi et al. [41]
Additive manufacturing (AM), information and communication technologies (ICT)	Reduced costs; reduced manufacturing time	Lastra et al. [45]
Sensing and communication technologies	Enabling condition-based maintenance; reduction in maintenance activities; reduction in financial expenditure; reduced spare parts usage; reduced usage of maintenance equipment and repair tools	Al Hanbali et al. [46]
AM	Reduced manufacturing time; reduced costs; production-on-demand regardless of complexity and type	Barbosa et al. [48]
Sensors and IoT technology, cloud computing, ML and AI algorithms	Reduced maintenance costs; reduced downtime of machinery and facilities; prediction of maintenance needs; increased profits; substantial competitive advantage	Gayialis et al. [49]
AM	Sustainability through increased resource efficiency; extended product life; reconfiguration of value chain; opportunities for direct analysis of product failures	Rupp et al. [50]
Storage system technology (ST)	Prediction of optimal decisions; improved resilience; improved data overview	Tufano et al. [51]

Table 2. *Cont.*

Industry 4.0 Technology	Benefits	Publication
Blockchain, information technology, RFID	Improved inventory control accuracy; improved visibility; improved traceability; purchase control; improved security; increased transparency; enabling of data sharing between relevant parties; effectiveness in decision making and maintenance planning; reduction in maintenance errors; establishment of accountability and disclosure between parties; elimination of labor excess and errors	Ho et al. [52]
AM, simulation technology	Greater customization possibilities; decentralized production; shorter supply chain lead times; improved operational flexibility	Xu et al. [53]
AM	Decreased lead time; improved continuity; increased profit and sustainability; low-cost manufacturing	Tuzkaya et al. [54]
IoT, ICT	Lower inventory costs; lower inventory levels; improved system performance; improved production efficiency; decrease in lead time	Lyu et al. [55]
AR, AM	Decrease in activities in the traditional logistics chain; reduced warehouse inventory; reduced number of errors; reduced spare part weight through AM; increased reliability	Ceruti et al. [56]
AM	Early prediction of spare part necessity; reduced electricity expenditure; reduced number of nonconformities in maintenance	Pelantova et al. [57]
IoT, Big Data	Increased transparency; increased flexibility; opportunity for continuous access to real-time information	Zheng et al. [58]

According to Table 3, there is an interconnectivity to the technologies presented. Several of them have similar or equal benefits. IoT and IIoT—alone and in combination with other Industry 4.0 technologies—empower predictive maintenance strategies, real-time resource data collection, and optimized decision making for replenishment and maintenance.

Hasan et al. [59] pinpoint the primary objective of IIoT to be maximizing the advantages of accumulated data that is collected from various devices. In predictive maintenance, sensor technology can be used to determine the remaining useful life (RUL) of machinery and set up accurate maintenance schedules [60]. However, there is little specific research on IIoT's role in warehouse logistics improvement specifically—while the general benefits of IIoT have been identified in various industries, its role in warehousing needs specification [61].

Liu and Ma [62] touch upon this gap in research on IoT in warehousing: they study IoT from a green and sustainable viewpoint, describing how IoT's efficiency effect in the warehouse leads to positive environmental impacts previously unseen in warehousing. Brunetti et al. [63] identify augmented reality and IoT as the most relevant Industry 4.0 technologies in warehousing. IoT is stated to support product traceability, storage condition monitoring, asset management, tracking of personnel, security, and warehouse facility conditions [63–70].

Table 3. The ten most cited publications from the literature search.

Focus of Publication	Publication	Journal	Number of Citations Listed in Scopus
Developing a prototype of a traceability system for food using blockchain and EPCIS.	Lin et al. [64]	*IEEE Access*	225
Enhancement of supply and value chains using blockchain technology in combination with IoT infrastructure.	Rejeb et al. [65]	*Future Internet*	194
Impact of augmented reality and additive manufacturing on maintenance in aviation.	Ceruti et al. [56]	*Journal of Computational Design and Engineering*	171
Proposal of an IoT infrastructure for collaborative warehouse order fulfillment.	Reaidy et al. [27]	*International Journal of Production Economics*	164
Proposal of communication architecture for farming using IoT technology.	Ferrández-Pastor et al. [68]	*Sensors (Switzerland)*	132
Systematically reviews recent research and applications of smart logistics based on IoT in areas like transportation, delivery, and warehousing.	Ding et al. [69]	*International Journal of Logistics Research and Applications*	113
Proposal of a blockchain-based system (managerial platform) for accuracy in recording spare parts traceability data in aviation.	Ho et al. [52]	*Expert Systems with Applications*	73
Analysis of additive manufacturing impact on sustainable business models using Industry 4.0 and its technologies.	Godina et al. [71]	*Sustainability (Switzerland)*	68
Presentation of a generic business process model for traditional and smart warehouses.	van Geest et al. [10]	*Computers in Industry*	61
Development of an HCI efficiency description in production logistics based on an interdisciplinary analysis.	Klumpp et al. [72]	*International Journal of Advanced Manufacturing Technology*	61

4.2. The Ten Most Cited Publications: Key Points and Benefits

After descriptive analyses of IoT and IIoT benefits, the publications in the search are sorted according to citation numbers. The ten most cited publications, shown in Table 3, are selected for analysis. Provided the novelty of this research field, an overview of the most influential concepts is necessary to understand the benefits, challenges, and lessons from IoT and IIoT usage in other industries.

The most cited publication, written by Lin et al. [64], develops a decentralized system rooted in blockchain and EPCIS to improve food traceability. Although further improvements to the system are suggested, it is found that the technologies perform greatly in tamper-proof ability, privacy protection, decentralization, and cost reduction of traceability measures. Rejeb et al. [65] show how IoT in combination with blockchain technology can bring forth new opportunities to enhance performance in supply chains. Ceruti et al. [56] suggest the integration of augmented reality and additive manufacturing with maintenance in the aeronautical industry. Reaidy et al. [27] show that an IoT infrastructure based on RFID technology can help in creating an ideal platform for decentralized warehouse management. Ferrández-Pastor et al. [68] present a communication architecture rooted in IoT technologies for farmers to develop smart systems. Ding et al. [69] find that IoT-based smart warehousing would be more efficient, visualized, accurate, streamlined, and secure, as opposed to traditional warehousing. Ho et al. [52] propose a blockchain-based system with IoT technologies for the tracing and condition tracking of spare parts for aircraft throughout the supply chain. Godina et al. [71] propose a framework and illustrate how additive manufacturing impacts sustainable business models. van Geest et al. [10] proved successful usage of Industry 4.0 concepts to develop an architecture for a smart warehouse. Klumpp et al. [72] establish the value of human–robot interaction and cooperation in decision making in production logistics.

Overall, the ten most cited publications use various methods and cases to develop solutions and ideas involving one or several Industry 4.0 technologies, including IoT, for the solving of industry-relevant issues. Interestingly, all publications appear in different journals, together reaching an audience covering large parts of the research communities in logistics, manufacturing, and sustainability.

4.3. Challenges in the Implementation of IoT, IIoT, and Other Industry 4.0 Technologies

In the comprehension and implementation of new concepts, technologies, and fundamentals, there are pitfalls present. Zoubek et al. [73] state that companies currently suffer from the following: a perception of Industry 4.0 as very complex, a lack of an understanding of what Industry 4.0 is, and a lack of ability to assess their capabilities in Industry 4.0. Such issues can prevent companies from adopting necessary measures for improved performance. Keh et al. [74] show that newly developed IoT-based systems often are complex for most users and only relevant for small-scale use, which can constitute challenges for large-scale production industries. Trstenjak et al. [75] describe how a lack of understanding of Industry 4.0 technologies can cause difficulties in developing the right transitional strategies for companies to move towards digitalized logistics processes, which can cause them to fall behind in technological advancement plans.

Challenges related to sustainable transition in industry often have a direct link to challenges with technology implementation. There is research suggesting that integration of Industry 4.0 technologies can be carried out rather seamlessly for internal use but is more difficult when combined with external actors and environments [76]. This has to do with IT system usage, digital maturity levels, and information sharing. In waste management, a solution proposal involving IoT suggested that electrical vehicle adoption included challenges like limited capacity, too much variation in operators, and battery power [77].

In finished goods logistics, some issues facing IIoT usage in tracking goods in a warehouse are the mixed distribution of functional zones and data fragmentation [78]. In IoT-based smart warehousing, developing countries face more issues pertaining to technology: labor skills, limited standardization, and restricted internet connectivity [79].

In intelligent warehousing, exact system development according to a warehouse's needs can be a time-consuming challenge [80], in addition to obsolete infrastructures and exposition to cyber attacks [81].

Table 4 shows various challenges associated with IoT, IIoT, and other Industry 4.0 technologies and their implementation in industrial practice. While research emphasizes the benefits of IoT and IIoT, several researchers include potential issues and pitfalls of Industry 4.0 technology implementation to caution against failure.

Table 4. Challenges associated with IoT, IIoT, and other Industry 4.0 technologies and their implementation in industrial usage.

Challenge	Publication
Improper use of sensors in IoT/IIoT	Lo et al. [82]
Collision of RFID tags for IoT	Zhong [83]
Lack of programmability; lack of software definition; lack of scalability	Zhang et al. [84]
Security issues; integration of new technology with existing ones; return of investment on new technology	Hamdy et al. [85]
Integration; successful transition from manual to digital; managing suppliers and distributors in the new digital system; reducing overall process time	Tahir et al. [86]
Laws, regulations, and policies regarding information sharing that can negatively affect IoT usage	Geng et al. [87]
Limited profitability in using Industry 4.0 technology in manufacturing when producing few items	Terelak et al. [88]
Privacy concerns over digital access; delays in work during downtime; network bandwidth; high energy consumption; interrupted service; resource constraints	Alwakeel [89]
Lack of purpose and desired business outcome in a company regarding IIoT usage	Liu et al. [90]
Increased electricity usage; increased maintenance costs; job losses; large initial investment; cyber security concerns with shared data	Nantee et al. [91]
Communication delays; sensor interference; hardware faults, especially when relating to automated guided vehicles (AGVs)	Chi et al. [92]
Increased workload when there are few items to work with	Dobos et al. [93]
Outdated supply chain strategies not suitable for new business environments with IoT	Chen et al. [94]
Granting access to appropriate users without compromising information and cyber security	Ho et al. [52]
Various technical, organizational, and ergonomic challenges (especially in relation to augmented reality (AR))	Rejeb et al. [95]
Complexity of IoT can result in improper usage and technical difficulties	Vukicevic et al. [96]
Lack of readiness for automation and digitization	Zoubek et al. [97]
Lack of professionals with thorough competence in information technology-enabled logistics	Wang [98]
Lack of an appropriate analytical framework upon which to base IoT usage	Tannady et al. [32]

Table 4 highlights the fear of industrial managers: the potential benefits of technology implementation also constitute the challenges. In Table 2, reduced costs were cited as a benefit. In Table 4, the research is clear that wrongful implementation and lack of planning can result in increased costs. Another benefit in Table 2 is reduced time expenditure. In Table 4, increased time expenditure and unnecessary time expenditure in cases of fewer parts for consolidation are listed.

It is the case for almost all the benefits and challenges: they are opposing sides to the same coin. The coin flip is the implementation work that is carried out by managers in the industry, and the upturned side will be the consequent result of the implementation work conducted.

The duality of technology implementation observed here provides a picture of reality: the slowness of the oil and gas industry to adapt to Industry 4.0 technologies usage in logistics is largely due to the high risk of failure. The benefits of implementation are as likely to be challenged if the implementation is not thorough, well researched, and planned in detail. The oil and gas industry is vital on a global scale. The high dependency society has on its consistent operations means that just-in-case policies in logistics activities are the safest for production. The implementation of new technologies would disrupt operations, require temporary halts in production, and reorganization of personnel and resources.

5. Practical Implications

In the past years, increased focus has been given to Industry 4.0 technologies and core concepts for improvement initiatives in various industries. The usage of such technologies' utilization in logistics activities—and the research on technology utilization in logistics activities—has also steadily increased. However, the oil and gas industry's involvement in such utilization and research is limited. Considering the industry's massive importance for humanity's energy supply needs, a higher level of research on the topic is desired.

This literature review contributes to the existing literature on IIoT and Industry 4.0 technologies usage in logistics activities in several ways. Firstly, it starts the conversation—as the first publication, per the authors' knowledge—on IIoT usage in warehousing in the oil and gas industry. More than 100 publications on IIoT and related Industry 4.0 technologies in similar use areas in other industries are analyzed to capture the essential existing knowledge as well as experiences that the oil and gas industry can learn from to gradually succeed with implementation without major pitfalls. Secondly, it serves as a strategy initiator for IIoT usage for managers and professionals in the field of logistics in the oil and gas industry. By analyzing the benefits and challenges, strategy pilots on implementation can be initiated through carefully constructed strategies. Finally, this study's contribution is to identify research gaps in the field of IIoT and Industry 4.0 technology implementation in spare parts warehousing in oil and gas.

Implementation of IIoT and related Industry 4.0 technologies in spare parts warehousing can have various implications. In Table 5, likely implications based on research and learnings from both similar and different industries are summarized.

Table 5. Practical implications of implementation of IIoT and other Industry 4.0 technologies.

Practical Implications	Publication
The more goods for handling, the more beneficial RFID technology is.	Du [99], Darwish et al. [100]
Per the perishable food industry, which has similarities with O&G, IoT has reduced inventory costs.	Maheshwari et al. [101]
IIoT reduces costs of spare parts in industrial robot maintenance.	Guo et al. [102]
O&G companies with production and activity in developing countries must consider issues related to limited connectivity before large-scale IIoT implementation.	Khalifa et al. [103], Trab et al. [104]
Service levels can improve in spare parts production when production is shifted to dispersed, interconnected facilities.	Haddad et al. [105], Lerher et al. [106]
Short-legged logistics problems can be solved with the usage of IoT and RFID technologies.	Xu et al. [107]
Storage of data gathered is possible both remotely for all stakeholders and locally on specific computers.	Wang et al. [108]
Warehouse design and purchase of appropriate technologies must be right the first time. Best to purchase correct items and implement gradually.	Yetkin Ekren [109], Kattepur et al. [110]
Goods sensing and location awareness are elemental contributions of correct technology implementation in the warehouse.	Zhao et al. [111]

Table 5. *Cont.*

Practical Implications	Publication
Appropriate product allocation can reduce warehouse costs by 10 to 16 percent.	Lorenc et al. [112]
Data consistency in real-time applications is an important consequence of proper IoT implementation.	Coito et al. [113], Gupta et al. [114], Kinnunen et al. [115]
Responsibility of managers that all implemented technologies are compatible with each other.	Borghetti et al. [116]
Deeper knowledge of warehouse operations can be obtained by "observing" operations through IoT and other technologies.	Jiang et al. [117], Kembro et al. [118]
Increased digitalization can lead to better communication between relevant departments within logistics activities.	Lin et al. [119]
IoT aids in reduction of time and finances spent on order picking.	Zhou et al. [120]
Managers could contribute to paving the way in their industries by implementing correct technologies, as many companies in several industries have inadequate levels of development in this area.	Čámská et al. [121], Mo et al. [122], Ellefsen et al. [123]
The information and communication technologies chosen to work together with IIoT are significant for IIoT's success.	Vimala et al. [124], Zhang et al. [125], Trab et al. [126], Zhang et al. [127]
Relationships with suppliers can and will change for the better if the right technologies are implemented in spare parts warehousing.	Taş et al. [128]
Appropriate technology implementation implicates decent location information of goods in the warehouse, all automated activities, a cohesive warehouse management system, workers' safety, accident prevention, and elimination of potential theft from the warehouse.	Zhao et al. [129], Jabbar et al. [130]
Cyber security can be increased to a high enough level for violation through viruses and Trojan horses to be near impossible.	Nadesh et al. [131]
Video monitoring of warehouses may be replaced by combining augmented reality and IoT usage.	Balamurugan et al. [132]
Several Industry 4.0 technologies in united usage can open possibilities for producing increased amount of necessary spare parts rather than purchasing from external suppliers.	Tuominen [133]

Spare parts warehousing in the oil and gas industry is unpredictable and complex. One example is an offshore installation in Norway built to produce 190,000 barrels of oil daily. The installation has a current register of 4000 spare parts. The suppliers are many, and the supplier contract types vary in scope depending on multiple factors. The main benefit IIoT and other Industry 4.0 technologies can provide the oil and gas industry in spare parts warehousing is predictability. Reducing the number of suppliers would be challenging even with IIoT and other technologies. Due to the high safety focus of the industry, all relevant spare parts should be registered and available on a just-in-case basis. However, predictability can influence the content of a contract, and thereby cost. This is especially the case for suppliers producing few parts that have low consequence classifications and a low probability of failure. The costs of these are considered redundant in the industry, and so higher levels of predictability eliminating such costs would be considered a benefit. This benefit has been proven several times by researchers examining successful examples from other industries and is applicable also in oil and gas.

Logistics processes often include spare parts of various classifications—some are necessary to always store due to their critical importance to machinery and processes in operations, while others are less critical in nature and should therefore be considered for just-in-time orders rather than just in case. Many spare parts are made of materials that can decrease in quality over time without usage, for example, through corrosion. Some spare parts are ordered from suppliers with close geographical locations, while others are shipped from far away to reach the warehouse for storage. There are many aspects to consider in spare parts warehousing in the oil and gas industry.

If implemented in the oil and gas industry, IIoT and other Industry 4.0 technologies usage must be tailored to the industry, specifically to the operations of the exact installation. This review shows that the importance of a solid, customized information and communication system at the root is elemental for success. Although several industries already have efficient information systems in use for warehousing, these may not be successful in oil and gas. The particularities of spare parts warehousing in oil and gas are specific, and the information and communication system operating for them should be as well. The primary learning from the research is still evident: IIoT and other Industry 4.0 technologies in spare parts warehousing in oil and gas can be valuable, given modern standardization.

Transitioning from traditional warehousing to a digital landscape can be the catalyst of a paradigm shift in operations and maintenance. Producing spare parts on demand and increasing the visibility of necessary spare parts across the value chain leads to less warehousing. A natural envisioned consequence of this is that the investment into predictive maintenance increases. Successful Industry 4.0 software usage in warehousing can quickly incorporate maintenance activities and reports, replenishment orders, and personnel time expenditure overviews. As oil and gas production companies usually use many different software, costing companies significant resources and money, streamlining software usage could change the very setups of the companies' digital departments.

IIoT has the ability to tie together information. It is likely that IIoT will be the enabling technology at the root of the paradigm shift. Many of the mistakes and safety incidents that occur in operations and maintenance in the oil and gas industry globally today happen due to a lack of information and miscommunication. With the removal of the human component, which is cultural and unreliable, logic can prevail.

A larger trend across industries is the care with which Industry 4.0 technologies such as artificial intelligence are treated. The boastful optimism industrial managers conveyed some years ago is fading. The warnings against total reliability on AI are rooted in experiments that reveal high failure rates. In Norway, oil and gas production companies have tested AI software reminiscent of ChatGPT and found several inaccuracies. This aligns with trends observed across industries: initial enthusiasm over new technologies fades as testing reveals inaccuracies, and thereafter the positivity increases carefully as the technologies are improved and implementation customized. Managers and decision makers in oil and gas production companies would likely be wisest to await implementation immediately after a technology's introduction and monitor and analyze for some time before implementation plans and measures are initiated.

Practical testing of IIoT and Industry 4.0 technologies along with modern software in a warehouse setting in oil and gas is vital for the progression of this research. This SLR reveals benefits and challenges as experiences and observed in other industries. It also reveals that a likely benefit of implementation quickly can become a pitfall. Testing and re-testing can decrease the likelihood of benefits becoming pitfalls. Gradual testing is both doable and recommended: gradually introducing different technologies to the tests will determine the success rates of each technology and clear the road ahead for managers to conduct trials.

6. Conclusions, Limitations, and Future Work

After analyzing a considerable body of research for our literature review, the conclusion is that there is potential for successful implementation of Industry 4.0 technologies, but practical research on implementation of technologies in spare parts warehousing in the oil and gas industry is needed. The authors' familiarity with the oil and gas industry in Norway allows for relevant knowledge of today's technology implementation in the industry, which is often initiated through small pilot projects. For this area of study, such smaller pilot projects are suggested as the basis for practical academic research.

This study provides a comprehensive analysis of the benefits and challenges of implementing IIoT and related Industry 4.0 technologies for spare parts warehousing in the oil and gas industry. A systematic literature review was conducted to gather research on the benefits and challenges of IIoT implementation from other industries. Collecting a total of 144 papers through Scopus, published between 2013 and 2023, the most relevant research on IIoT and other technologies was conducted to lay the foundation for the oil and gas industry to optimize its logistics processes in the near future. The findings show that there are multiple considerations to take before implementation and usage. As many benefits as there are, the pitfalls are poignant. This requires significant planning, testing, and consideration by managers and teams. In the oil and gas industry, spare parts warehousing is a time- and capital-consuming activity that can be optimized greatly by IIoT usage. However, as important as the technology implementation is, the significance of solid information and communication technology to run the overview of operations should not be underestimated. Success in IIoT implementation in spare parts warehousing is reliant on customization of connected information technologies; for large-scale production industries like oil and gas, there is uniqueness in daily operation. The challenges stated in our study show that each industry has its own characteristics to which new initiatives must be adapted rather than copied from other industries. However, the benefits that result from potential success are significant, and therefore the work is encouraged.

One key limitation of our literature review to be considered is the exclusion of all but peer-reviewed journal papers. There may be book chapters, conference proceedings, and student theses containing content potentially relevant to our study. These were excluded in this research to ensure the academic integrity of included works. We acknowledge that there may still be relevant content present in non-peer-reviewed literature.

There is much potential for future work. Mentioned pilot projects from Industry 4.0 technology implementations in oil and gas logistics are required for examples of how they would work in practice. Such case studies can be rooted in simulations as well as reality. Cost analysis work relating to Industry 4.0 technology usage should be conducted. Research on different technology suppliers and their suitability with logistics operations in oil and gas is also desirable, for professionals to use in real-life implementation. Literature reviews focusing more on other Industry 4.0 technologies, such as robotics or additive manufacturing, can be conducted. Operational research work on supplier shipments to oil and gas spare parts warehouses can also be conducted to exemplify or justify Industry 4.0 technology usage in warehousing.

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