IIoT and Other Industry 4.0 Technologies in O&G

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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.

industrial internet of things (IIoT) | industry 4.0 | oil and gas industry | warehouse | spare parts

1. Benefits of Implementation of Internet of Things and Industrial Internet of Things and Other Industry 4.0 Technologies

The traceability feature of Internet of Things (IoT) enables benefits such as reliability, fast response time, efficiency, and accuracy [1]. In maintenance work, IoT or Industrial Internet of Things (IIoT) has been used to feed data to digital twins where whole systems can be monitored [2]. 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 [3]. 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 [4]. Across industries, Tannady et al. [5] state that IoT's uses and benefits within logistics are limitless.

According to Jarašūniene et al. [6], 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 [7]. In healthcare, IoT in combination with blockchain and cloud computing secures the storing of health records, whose benefits are transparency and decentralization [8]. 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 [9].

Talpur et al. [10] 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. [11] 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 [12]. Human factors in synchronization with technology are considered essential for operational success, particularly in warehouse order picking [13].

In spare parts inventories, IoT provides a unique opportunity for the prediction of future maintenance needs [14]. 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 [15]. 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. [16] state the benefits of IoT in logistics activities as facilitation of data exchange, communication between elements, and remote monitoring. Sahara et al. [17] explain that enhanced control, improved performance in the supply chain, and increased customer satisfaction are among the main benefits of IoT. Lastra et al. [18] claim that Industry 4.0 technologies add value to the entire product life cycle. Al Hanbali et al. [19] 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 1** shows the benefits of IoT and other Industry 4.0 technologies as stated in the literature related specifically to spare parts management.

Table 1. 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. [2]
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. [3]
Machine learning (ML)	Reduction in error of time-to-failure predictions; improved response time through data dimensionality reduction	Elmdoost-gashti et al. [20]
IoT	Reduced costs; increased reliability; increased prediction accuracy; improved opportunities for driving decision models for maintenance and replenishment actions	Shi et al. [14]
Additive manufacturing (AM), information and communication technologies (ICT)	Reduced costs; reduced manufacturing time	Lastra et al. [18]
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. [19]
AM	Reduced manufacturing time; reduced costs; production-on-demand regardless of complexity and type	Barbosa et al. [21]
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. [22]
AM	Sustainability through increased resource efficiency; extended product life; reconfiguration of value chain; opportunities for direct analysis of product failures	Rupp et al. [23]
Storage system technology (ST)	Prediction of optimal decisions; improved resilience; improved data overview	Tufano et al. [24]
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;	Ho et al. [25]

Industry 4.0 Technology	Benefits	Publication
	reduction in maintenance errors; establishment of accountability and disclosure between parties; elimination of labor excess and errors	
AM, simulation technology	Greater customization possibilities; decentralized production; shorter supply chain lead times; improved operational flexibility	Xu et al. [26]
AM	Decreased lead time; improved continuity; increased profit and sustainability; low-cost manufacturing	Tuzkaya et al. [27]
IoT, ICT	Lower inventory costs; lower inventory levels; improved system performance; improved production efficiency; decrease in lead time	Lyu et al. [28]
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. [29]
AM [32]	Early prediction of spare part necessity; reduced electricity expenditure; reduced number of nonconformities in maintenance	Pelantova et al. [30]
IoT, Big Data	Increased transparency; increased flexibility; opportunity for continuous access to real-time information	Zheng et al. [31]

Keh et al. [33] 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. [34] 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 [35]. 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 [36].

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 [37]. In IoT-based smart warehousing, developing countries face more issues pertaining to technology: labor skills, limited standardization, and restricted internet connectivity [38]. In intelligent warehousing, exact system development according to a warehouse's needs can be a time-consuming challenge [39], in addition to obsolete infrastructures and exposition to cyber attacks [40].

Table 2 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 2. 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. [41]
Collision of RFID tags for IoT	Zhong [42]
Lack of programmability; lack of software definition; lack of scalability	Zhang et al. [43]
Security issues; integration of new technology with existing ones; return of investment on new technology	Hamdy et al. [44]
Integration; successful transition from manual to digital; managing suppliers and distributors in the new digital system; reducing overall process time	Tahir et al. [45]
Laws, regulations, and policies regarding information sharing that can negatively affect IoT usage	Geng et al. [46]
Limited profitability in using Industry 4.0 technology in manufacturing when producing few items	Terelak et al. [47]
Privacy concerns over digital access; delays in work during downtime; network bandwidth; high energy consumption; interrupted service; resource constraints	Alwakeel [48]
Lack of purpose and desired business outcome in a company regarding IIoT usage	Liu et al. [49]
Increased electricity usage; increased maintenance costs; job losses; large initial investment; cyber security concerns with shared data	Nantee et al. [50]
Communication delays; sensor interference; hardware faults, especially when relating to automated guided vehicles (AGVs)	Chi et al. [51]
Increased workload when there are few items to work with	Dobos et al. [52]
Outdated supply chain strategies not suitable for new business environments with IoT	Chen et al. [53]
Granting access to appropriate users without compromising information and cyber security	Ho et al. [25]
Various technical, organizational, and ergonomic challenges (especially in relation to augmented reality (AR))	Rejeb et al. [54]
Complexity of IoT can result in improper usage and technical difficulties	Vukicevic et al. [55]
Lack of readiness for automation and digitization	Zoubek et al. [56]

Challenge	Publication
Lack of professionals with thorough competence in information technology-enabled logistics	Wang [57]
Lack of an appropriate analytical framework upon which to base IoT usage	Tannady et al. [5]

ation also clear that s reduced time expenditure. In **Table 2**, 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.

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