Warehousing in the Context of Digital Supply Chain in the Oil and Gas Industry: Using Grounded Theory to Create Groundwork

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Abstract. The oil and gas industry is a complex industry with many stakeholders, risks, and monetary values involved. The supply chain of oil and gas companies is an aspect of oil and gas companies that has developed without major optimization measures along the way – it has simply had activities and concepts added as they have come along. One such activity in the supply chain in need of optimization is warehousing. A large amount of spare parts cost oil and gas companies extensive amounts yearly. With the introduction of the digital supply chain, the oil and gas industry is looking to add lessons and concepts to decrease costs, increase sustainability, and optimize warehouse activities. As this is a research field in which little specific work has been conducted, we use grounded theory to develop groundwork upon which companies can rebuild their warehousing and other supply chain activities. We conclude the work with suggestions for future research.

Keywords: Warehousing, digital supply chain, spare parts inventory, oil and gas, Industry 4.0, grounded theory

1 Introduction

In the past few years, some research on digitalization in the oil and gas industry has been conducted. Arguments have been made in favor of introducing modern technologies into many branches of the industry. There have particularly been substantial proof of technology usage benefitting the oil and fluids production phase [1], [2], [3]. However, the total amount of research on digitalization in oil and gas is still limited compared to many other industries [4]. One area within the sector where research appears to be severely limited thus far is the supply chain. Digitalization of the supply chain has been linked to better overall performance in other industries, prompting less digitally mature industries to want to follow suit [5]. The specific supply chain activity we would like to focus on in this research is warehousing. Warehousing is used for many items and purposes in the industry, one of which is spare parts warehousing [6]. It serves a

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key function in the supply chain, ensuring the continual availability of spare parts for offshore production. Such production at offshore facilities constitutes a high level of risk, and unpredicted malfunction in equipment and machinery can occur. In addition to this, planned maintenance activities are performed continuously to ensure safety of personnel and production. In both cases, spare parts are key to ensuring quick and safe resumption of regular production. Adding to that, technology implementation can increase the chances of achieving successful predictive maintenance and thereby limit the chances of unplanned production halts due to equipment failure. Some Industry 4.0 technologies allow for predicting and forecasting based on data, which holds a potential for the industry to decrease costs and streamline activities.

According to Mol [7], increasing visibility across the supply chain is key to eliminating many of the issues observed in industrial supply chains in the past years. Increasing visibility can be done through digitalizing the supply chain [8]. In this paper, we aim to provide an example of how grounded theory as a methodology can be used to outline the components of spare parts warehousing in the oil and gas industry in the context of digital supply chain. In essence, this means identifying the building blocks, mindsets, and technologies that should be included in the future of digitalized spare parts warehousing in oil and gas. The work will be on the basis that both warehousing and other supply chain activities in the industry are in adherence with the concepts of digital supply chain as presented in recent literature. To achieve this, we start with introducing the background on the topic, presented in Section 2. Thereafter, we outline the methodology and data sources in Section 3. Finally, we discuss our research approach and conclude by suggesting further research in Section 4. Separately, an article on groundwork and key components resulting from this research is published.

2 Background

Supply chains relating to oil and gas production are complex [9]. The frequent use of single-source suppliers, great amounts of material warehousing, operational limitations, and non-resilient distribution networks consitute some of the main challenges in the oil and gas supply chain [10]. However, some analysts claim that digitalization has the potential of eliminating challenges in the supply chain [11].

Spare parts warehousing in the oil and gas industry is a topic many supply chain workers in the industry work with. As the primary products from the industry are extracted from raw material rather than being manufactured in a factory, there is a uniqueness to warehousing practices and concepts compared to other classic manufacturing industries. The uncertainty relating to offshore production is rooted in function, safety, environment, and monetary considerations. The spare parts warehouse should go through optimization work to decrease inventory levels, yet there should be secure inventory levels in cases of emergency and unpredictable circumstances. Establishing clear practices in warehousing then is challenging – there is no foundation, criteria, or strategic framework to guide managers and decision makers. This is what our work wishes to address: a starting point for optimization of oil and gas spare parts warehouses in a disruptive era.

3 Methodology and Data Sources

Grounded theory is a qualitative research methodology that traditionally has been used in social sciences, but in the past two decades has gained traction also in management science, engineering, and science research.

Grounded theory was introduced by Glaser and Strauss in 1967. It describes a qualitative method that inductively generates theory from data [12]. Data in this case refers to everything – literature, images, qualitative and quantitative data, and videos. They described that the aim of grounded theory is to generate theory rather than validate existing theory. Further, they specified that it is an inductive research method, often useful in exploring little-researched fields that require fundamental theories for future research to be able to build upon.

An integral component of grounded theory is data collection and analysis. Data constitutes the foundation upon which theory is developed and generated. The qualitative approach we use in our research is rooted in the following types of data:

i. Existing information and concepts in published literature
ii. Warehouse layout example (from a Norwegian onshore oil and gas warehouse) modeled in simulation software

Classic Glaserian grounded theory involves awaiting research question definition, as the aim is for the RQ to "emerge" from the data and the work. Instead, we define the problem concept, and develop our research from there. By adhering to Glaserian principles, we also ensure a strategic use of coding. This means classifying data into the two categories "published literature" and "learnings from warehouse layout simulation", and eventually "discovering" a theory that naturally emerges from the classification of data.

The problem concept is to develop groundwork for oil and gas companies to develop and maintain warehouse operations – especially spare parts management – that are in accordance with the digital supply chain. The energy transition will require the oil and gas industry to consider many measures, extensive technology implementation among them, to reach sustainability goals set by governments and corporate executive committees.

3.1 Data: relevant literature

Ivanov et al. [13] dedicate the first part of their book, *Global Supply Chain and Operations Management: A Decision-Oriented Introduction to the Creation of Value,* to defining supply chain and supply chain management. They define a supply chain as a network of organizations and processes where all are contributors to the production and delivery of final products. Further, they define supply chain management as the integration and coordination of material, information, and financial flows for transformation and use of supply chain resources in the most rational way along the value chain, from raw material supply to customers.

In the oil and gas industry, the final products sold to customers are oil and gas. Along the way, there are multiple supply chain components, but also multiple supply chains, that contribute to the realization of final sales and delivery. Fig. 2 shows a simplified chart of the oil and gas supply chain, as per Ivanov et al.'s definition.

Fig.2. Simplified oil and gas supply chain.

The digital supply chain does not necessarily remove components along the supply chain. For the oil and gas industry, it can be difficult to envision any of the components from Fig.1 being removed – the nature of the end product is such that it must pass through certain stages before it reaches the end customer. Rather, the digital supply chain is often characterized by new capacities, automated architectures, and increased efficiency of information technologies [14].

The digital supply chain's aim is to integrate digital and physical worlds to achieve a transformation of the traditional supply chain for the sake of optimization [15]. The concept of lean is often mentioned in regard to digitalization, and so is increased sustainability – the latter being a key selling point, as many industries seek to reduce their emissions and be more environmentally conscious [16]. In relation to digital supply chain, literature mentions concepts like Industry 4.0 [17] and smartness [18] to emphasize its modernity and potential.

MacCarthy and Ivanov [18] uncover the potential that lies in combining traditional supply chain practice with practices and technologies of the digital supply chain. An illustration of such is given in Fig.3.

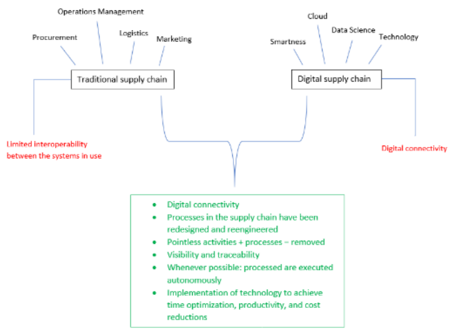

Fig.3. Combining traditional supply chain with digitalization measures.

When it comes to warehousing, this involves several steps. According to de Koster et al. [19], these are receipt, put-away, storage, order-picking, value added services, packaging, and shipping. These activities all take place within the warehouse periphery, but are affected and further influence all other activities along the supply chain: production of items, shipping for storage in warehouse, refining, and procurement. Therefore, its efficient performance is key.

There are many warehouse decisions, made by managers and directors, that shape warehouse operations. These come in addition to the traditional steps that are conducted on a daily basis, and shape the direction of the warehouse processes [19]. Such directions can include warehouse size, warehouse layout, and number of human workers in the warehouse.

In many industries, including the oil and gas industry, warehouse directions are largely set. Their warehouses have been in operation for several years. However, these decade-old practices can cause companies to miss out on cost reductions. As the world of technology has progressed, smart warehouse management has increasingly become a popular concept and been implemented in industries like e-commerce [20]. Astonishingly, according to Boysen et al. [20], streamlining of warehouse processes through technology implementation can lead to significant cost savings. This happens because technology implementation can lead to removal of superfluous activities, immediate identification of bottlenecks, and continuous visibility and communication between stakeholders, warehouse operators, and other relevant personnel. Although specifics can differ from industry to industry, Masae et al. [21] identify inventory management, routing, stroage assignment, batching, and zoning as highly important management decisions in warehousing.

One of the most, if not the very most, important component that would allow for digital supply chain to be realized in warehousing is Industry 4.0 technologies [22]. Since their emergence, they have been researched extensively, both conceptually and practically. Suggestions have been made in literature for their implementation in various industrial supply chains, as well as in other processes and parts of the value chain. Industry 4.0 technologies are largely considered to be an essential part of the future, especially in industrial practice [23].

Literature identifies several technologies that can be identified as Industry 4.0 technologies. We choose to look at all relevant technologies. This is best done by dividing them into sub-groups of related technologies. We estabish three such sub-groups:

i. Digital platforms
ii. Analytics
iii. Emerging technologies: Industrial Internet of Things (IIoT), digital twin, and additive manufacturing

3.2 Data: Warehouse layout simulation

To validate the concepts from gathered literature, we run a simulation of a real-life oil and gas spare parts warehouse in Norway. The layout from the warehouse is inserted into Visual Components 4.4 Premium, a software that uses a combination of process flow and Python programming to generate simulations. Into this layout, we place the technologies presented in Section 3.4.3.3: IIoT, AM, and digital twin. Prior to the insertion of technologies, only shelves containing storage items were present in the layout.

We observe whether the digitalization measures suggested in literature “work”. This is tested by inserting the following technological tools into the warehouse layout: an additive manufacturing printer, a mobile robot, an automated guided vehicle (AGV), and an autonomous industrial mobile manipulator (AIMM). Additionally, all items – technological tools, shelf items, and the items’ shelf position – are interconnected in the simulation. The robots performing order picking know which item to pick, the exact shelf placement of the item, when to pick it, where to deliver the item for consolidation, and when to pick from consolidation and bring to shipment. The setup of the simulation is shown in Fig.4.

The interconnectivity is enabled through IIoT. In the simulation, IIoT connection is achieved in connecting technology and items through programming. The programming allows for independent communication, as IIoT does. Digital twin is in this case the simulation itself. The duplicate of the warehouse allows for testing of technology and optimization measures where parameters like batch size and robot velocity can be altered. Interconnectivity is a key feature of digital supply chain, and simulations that allow for testing of optimal interconnectivity make useful test cases before implementation.

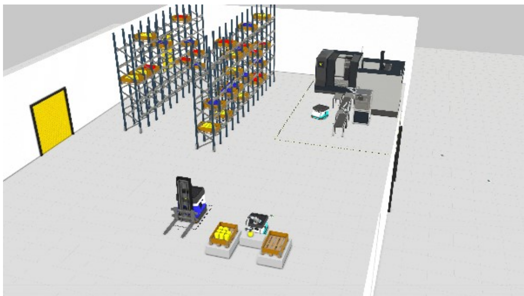

Fig.4. Simulation setup of an oil and gas spare parts warehouse with technology.

The AGV brings one pallet from a shelf to a consolidation area. Then, the AIMM picks an item from the pallet. While this is occurring, the additive manufacturing system in the corner of the warehouse is producing spare parts. An AIMM brings the additively manufactured part to the pallet in the consolidation area once its production has finished. Once all parts – from shelves and AM station – have been placed on the pallet, the AGV transports the pallet to the shipment area placed outside the warehouse.

The simulation is run for a fixed time frame, and with varying item numbers per shipment. These variables are set with real operations in mind. The variation in shipment item number closely reflects warehouse operations for the oil and gas industry, where supply and demand numbers can vary.

A high level of flow, agility, predictability, and visibility are implied as key components of successful digital supply chains. We deduce that our simulation is inclined towards these concepts. During normal operations and appropriate function of technology, flow is present. We observe that flow to a significant extent is enabled by IIoT. Everything – parts, technologies, shipment data, plans, and routes – are connected. It is first and foremost the interconnectivity of the technologies and the relevant information rather than the presence of the technologies that allows for the achievement of digitalization and flow. The technologies without the interconnectivity enabled by IIoT could cause an opposite effect: high extent of human involvement, increase in time expenditure, and inability of flow.

4 Discussion and conclusion

We gathered data from literature and a warehouse operation simulation to create groundwork for the oil and gas industry to implement digital supply chain measures. We used concepts from grounded theory to deduce which components and concepts are important for the oil and gas industry to succeed with digital supply chain implementation in spare parts warehousing for offshore production installations. The resulting concepts from the grounded theory work are presented in a separate paper.

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