# Digitalized Manufacturing Logistics in Engineer-to-Order Operations

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**Abstract.** The high complexity in Engineer-To-Order (ETO) operations causes major challenges for manufacturing logistics, especially in complex ETO, i.e. one-of-a-kind production. Increased digitalization of manufacturing logistics processes and activities can facilitate more efficient coordination of the material and information flows for manufacturing operations in general. However, it is not clear how to do this in the ETO environment, where products are highly customized and production is non-repetitive. This paper aims to investigate the challenges related to manufacturing logistics in ETO and how digital technologies can be applied to address them. Through a case study of a Norwegian shipyard, four main challenges related to manufacturing logistics are identified. Further, by reviewing recent literature on ETO and digitalization, the paper identifies specific applications of digital technologies in ETO manufacturing. Finally, by linking manufacturing logistics challenges to digitalization, the paper suggests four main features of digitalized manufacturing logistics in ETO: (i) seamless, digitalized information flow, (ii) identification and interconnectivity, (iii) digitalized operator support, and (iv) automated and autonomous material flow. Thus, the paper provides valuable insights into how ETO companies can move towards digitalized manufacturing logistics.

**Keywords:** Engineer-to-Order · Digitalization · Manufacturing logistics

## 1 Introduction

The need for coordination of material and information flows in ETO operations is significant [1] and tailored approaches are required for an effective and efficient management of manufacturing operations [2]. Several studies have been aimed at addressing the challenges related to manufacturing logistics in different ETO cases, however, the aspect of digitalization has not yet been sufficiently addressed in this type of manufacturing environment [3].

The new, digital technologies within Industry 4.0 has the potential to change the manufacturing industry by enabling new and more efficient processes. Concepts and developments such as the Internet of Things (IoT), Cyber-Physical Systems (CPS), augmented reality, artificial intelligence and big data analytics are expected to lead to a paradigm shift in industrial manufacturing [4]. Digitalization emerges as a way of managing complexity, and is introduced as one of the main areas for future research in


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complex ETO manufacturing [3]. With the high complexity in these manufacturing environments, there is a need to investigate how digitalization can improve manufacturing logistics performance. Therefore, this paper aims to identify how digital technologies can be applied in order to address the challenges in ETO manufacturing logistics.

The remainder of this paper is structured as follows. Section 2 presents and describes the characteristics of ETO manufacturing logistics. Thereafter, a case study serves to identify specific manufacturing logistics challenges. Applications of digital technologies in ETO is then identified through reviewing literature, before digitalization and manufacturing logistics challenges are linked in Sect. 5. The paper ends with the conclusions, limitations and further research in Sect. 6.

## 2 The Characteristics of Complex ETO Manufacturing

Manufacturing logistics concerns the coordination of the operations related to the flow of materials through the manufacturing departments up to the production of the end product [5]. Achieving cost-efficient manufacturing logistics in ETO is challenging due to the characteristics of the manufacturing environment [6]. With the ETO approach the activities of design, engineering, as well as the actual production processes, are performed after an actual customer order has been received. The customer order decoupling point is located at the design stage, with actual customer orders driving the production [7]. The large degree of customization, the product structure complexity, and the overlapping of manufacturing and design activities are reasons for a very high complexity of the internal ETO supply chain [8].

The most complex type of ETO manufacturing, which is the main focus of this paper, is the production of one-of-a-kind products [9]. Producing unique products every time has major implications for the manufacturing logistics processes, such as production control, as it creates a dynamic, uncertain and complex manufacturing environment [10]. Table 1 presents the main characteristics of complex ETO manufacturing.

**Table 1.** Main characteristics of complex ETO manufacturing.

| |
|---|
| Product characteristics: |
| • Big-sized, complex products with deep product structures [3, 11] |
| • High level of customization [9] |
| • High product variety and low volume on product level (one-of-a-kind products) [2, 9] |
| Process characteristics: |
| • Manufacturing carried out as large projects in fixed position layouts [9] |
| • Frequent changes [11] |
| • Highly integrated and overlapping activities [12] |
| • Focus on flexibility [11] |
| Market characteristics: |
| • Customer order decupling point located at the design stage [7] |
| • Fluctuations and uncertainty in mix and sales volume [10] |
| • Uncertainty in product specifications [10] |

## 3 Manufacturing Logistics Challenges in Complex ETO

To get empirical data on how the characteristics of ETO manufacturing are affecting manufacturing logistics, a case study of the Norwegian shipyard Ulstein Verft AS (UVE) was conducted. Case data was collected through semi-structured interviews, observations at the yard and background data on the company from several years of research collaboration. This section includes a brief description of the case company and its manufacturing logistics.

UVE is part of Ulstein Group ASA, a Norwegian industrial group with activities in ship design and shipbuilding. The group's main business consists of designing and building highly customer-specific vessels, typically advanced offshore vessels such as supply vessels, anchor-handling vessels, offshore construction vessels and seismic vessels, in close collaboration with the customers. In recent years, they have also started building expedition cruise ships, yachts and passenger ships, in addition to ships for the offshore wind industry and developing designs for fishing vessels. UVE is the shipyard responsible for outfitting the ships delivered by the group. The hull production is carried out at a foreign yard, before the hull is towed to UVE in Ulsteinvik, Norway.

The production at UVE is a highly complex ETO production and the characteristics of the production environment at UVE bear a close resemblance to the ETO characteristics presented in Table 1. In general, there is a highly complex material and information flow related to outfitting activities at UVE, with non-repetitive and non-routine work processes. This is a result of the complex production of one-of-a-kind products, and a high uncertainty in process specifications. Moreover, processes are prone to disruptions due to changes occurring after the outfitting activities has started. This affects the planning, scheduling and sequencing of tasks, the supply of materials and the supporting documentations needed by operators to perform jobs. It is today challenging to achieve the tight integration of IT systems needed for efficient outfitting of the ships.

Paper-based documentation of product models and drawings are critical sources of information for operators in this type of manufacturing. Operators have a particularly important role in performing the outfitting activities at UVE, as standardization and automation of processes is difficult due to the non-repetitive type of work. Many operations are thus manual, including production processes, material handling and internal transportation of materials. Providing the required information to operators is further complicated when changes occur, as models and drawings then must be updated accordingly. Furthermore, it is difficult to have an overview of the yard from a manufacturing logistics perspective as operations are spread across a vast area. Materials, tools and equipment are thus geographically dispersed, and operators spend a considerable amount of time walking to collect or search for them.

From this, four main manufacturing logistics challenges at UVE are derived:

- IT system integration and sharing of up-to-date information
- Localization of materials, equipment and tools
- Complex and information demanding work for operators
- Manual material handling and irregular and disrupted flows.

## 4 Digital Technologies in ETO Manufacturing Logistics

Digital technologies emerge as promising means for managing complexity. While the technical developments of these technologies are rapidly advancing, applications in ETO still lags behind and requires research focus [3]. To have a structured overview of the available technologies and their features, eight technology groups were identified by integrating the technology clusters of smart manufacturing [13] and the nine advances in technology forming the foundation for Industry 4.0 [14]. This is shown in Table 2.

**Table 2.** Overview and description of digital technologies.

| Tech. group | Description |
|---|---|
| Autonomous robots | Automatic Guided Vehicles (AGVs), Autonomous Mobile Robots (AMRs), and Collaborative robots (COBOTS) for material handling and performing logistics operations |
| Integration of IT systems | Horizontal and vertical integration of IT systems for production management (PLM, ERP, MES) |
| Internet of Things | Objects equipped with sensors and actuators, enabling storing and exchange of information through network technology |
| Cyber security | The secure and reliable protection of industrial production systems from cyber threats |
| Cloud manufacturing | Cloud-based solutions for sharing and exchange of data between systems, sites, and companies |
| Visual technology | The visual representation of an object, in the form of augmented reality (AR) through superimposing a computer-generated 3D image in the real world, creating a virtual reality (VR) or projecting 3D images as holograms |
| Data analytics | Transforming data into knowledge and actions within a manufacturing system. Big data for analysis of large sets of real-time data, artificial intelligence, machine learning and advanced simulations are all part of this group |
| Additive manufacturing | 3D printing of objects layer by layer, based on 3D models or CAD files of the objects |

Reviewing recent literature on ETO manufacturing and digitalization has identified a range of possible applications of these technologies. These are described in the following paragraphs of this section.

Several different IT systems are used at the different levels of today's manufacturing systems, but these are often not fully integrated [14]. However, the current technological developments in ICT increases the opportunity of achieving such an integration. Also in one-of-a-kind production, fully integrated, digitalized factories are possible through integrated sensor networks and supporting information systems [15]. Enhancing integration between modeling, scheduling and monitoring processes is particularly relevant for ETO [16]. Eventually, everything should be connected to a cloud-based solution and also taking the aspect of cyber security into account [17].

Digital technologies can be applied to assist operators to become smarter [18], and this is particularly relevant considering the high operator density in complex ETO. Visual technology such as Augmented reality [19] is one example of operator support that can enable schedules, product models and work instructions to be displayed on tablets or AR-glasses. Integration of such mobile devices with higher-level enterprise systems enables rapid sharing of updated information to the production floor. Such digital interfaces will also enable updating status of tasks through mobile devices, thus digitalizing progress reporting. Building Information Modeling (BIM) for information sharing through "BIM kiosks" is another means to provide operators with fast access to digital product models available from the PLM system [20].

Several papers have investigated the use of RFID for identification, localization and tracking [15, 19, 21]. Tracking and localization technology for automated data capturing of materials movement can enable real-time planning and control [15] such as real-time monitoring of assembly processes [22]. Furthermore, the integration of e.g. RFID, GPS and GIS technology with AR technology allows operators to get information on the location of materials, tools and equipment on mobile devices such as smart glasses or tablets. Drones is another possible application for localization purposes, as they can be utilized for inspection of the overall status of the shipyard [23]. Combining drones with 3D photography can then be used to provide 3D footage of the yard.

Although 3D printing mainly concerns production technology, such applications are also relevant for manufacturing logistics as it provides an ability for suppliers to send part designs to the yard for printing at the yard [23]. Moreover 3D printing can be used for printing of tools and equipment on the spot [23], hence it can reduce the time operators spend walking to acquire the tools and equipment necessary to perform a job.

Automated solutions for material handling are however the most promising developments to reduce time spent walking, waiting and searching. Automation of production processes, material handling and transportation of materials and equipment on the production floor has traditionally been difficult in complex ETO. However, with the increased flexibility of automated solutions today, the possibilities to automate such activities are increasing, exemplified by the use of AGVs, mobile robots, collaborative robots and automated material handling and feeding [24].

## 5 Features of Digitalized Manufacturing Logistics in ETO

Having identified various applications of digital technologies in ETO, it is now possible to link these to the manufacturing logistics challenges. Each of the identified challenges are here linked with a feature that can be provided by digital technologies.

The close integration between engineering and production in ETO manufacturing requires integrated IT systems for the efficient control and execution of manufacturing logistics activities. Moreover, with product changes occurring after production has started, it is necessary to provide operators with updated product drawings and models. Efficient information sharing is also required in the opposite direction, from shop floor to higher level IT systems, e.g. status and progress reporting from the production floor. With these challenges, there is a need for a *seamless, digitalized information flow*, where all subsystems at the various levels of the manufacturing system are integrated. Information should flow continuously from the production floor via MES system up to higher-level IT systems, such as the ERP system. This gives access to real-time information for planning and controlling operations.

The complexity of ETO products, with their deep bill of materials, makes it challenging to maintain an overview of all materials, equipment and tools necessary to perform operations. They are geographically dispersed across the facility, and workers often spend time searching for these assets, as well as walking over significant distances to acquire them. These challenges related to localization of materials, equipment and tools requires that *Identification and interconnectivity* is provided through digital technologies. It is now to a large extent possible to identify and interconnect objects in a facility through the utilization of new technology, and this will enable a highly integrated way of managing operations. Identification technology, networking technology and equipping products with sensors are keys to create a connected factory.

Operators in ETO manufacturing facilities such as UVE's shipyard must perform a range of highly complex, manual and non-routine tasks, as products are one-of-a-kind. Information about products, assemblies, processes etc. are therefore critical for the operators for them to be able to perform the scheduled tasks and activities. Digitalized manufacturing logistics should therefore include *digitalized operator support*. Human workers will still be important in a digitalized shipyard, and digital technologies should therefore be utilized to provide enhanced support for them, giving rapid and easy access to required and up-to-date information about the processes and activities.

With the manual material handling and irregular and disrupted material flow, there is a need for a more *Automated and autonomous material flow*. Products, components, tools, equipment and other objects can then be transported more efficiently, and with less human intervention. In manufacturing logistics, digital technologies can bring autonomy and automation to the physical flow of materials.

Figure 1 shows the manufacturing logistics challenges identified from the case study, and their corresponding required features of digitalized manufacturing logistics.

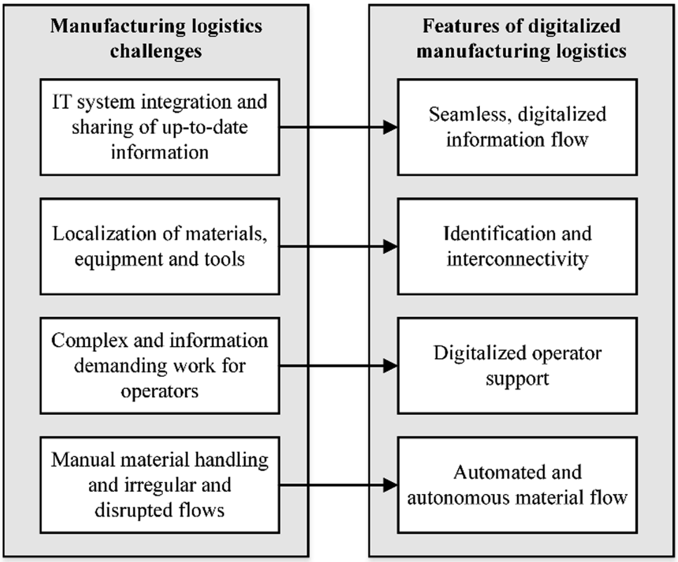


**Fig. 1.** ETO manufacturing logistic challenges and corresponding required features of a digitalized manufacturing logistics system.

## 6 Conclusions, Limitations and Further Research

This paper has identified a number of manufacturing logistics challenges in ETO manufacturing. It has further linked these to a set of required features of a digitalized manufacturing logistics system, outlining the needs that should be met by digital technologies. To be able to address the manufacturing logistics challenges in ETO there is a need for seamless, digitalized information flow, identification and interconnectivity, digitalized operator support, and automated and autonomous material flow. Digital technologies can enable these features, and there is a range of possible applications also in ETO. For digitalized manufacturing logistics in ETO several of the technologies should be applied and combined. Although there is still a lack of research on digitalization in ETO manufacturing [3], this paper identifies a range of digital technologies that has been applied or described conceptually for this type of manufacturing.

Further work related to this research will focus on developing more concrete descriptions of how the digital technologies can be implemented in the case company, and estimate the benefits in terms of relevant and measurable performance indicators such as time, cost, flexibility and quality. Future research should also include case studies of ETO manufacturers with similar characteristics as the case company in this paper, in order to generalize the findings.

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