Towards a concept for digitalized yard logistics—outlining the next-generation features

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Abstract. Yards are industrial sites for production and servicing of ships and offshore maritime installations, such as oil and gas platforms and modules, offshore windmills, and fish farms—all essential products in the maritime industry. Although many yards are performing highly complex and technically advanced production, there is still a need to bring the internal logistics of yards to a corresponding level of advancement. Industry 4.0 technologies may answer this need, and this paper presents a concept for digitalized yard logistics. The concept is developed through a concept development activity inspired by design science research, based on a multiple case study of 8 Norwegian yards, including shipyards and offshore construction yards. By mapping these yards, in particular their current level of digitalization, we propose a concept grounded in practice. The concept is built upon four main features of digitalized yard logistics: i) seamless, digitalized information flow, ii) identification and interconnectivity of objects, iii) digitalized operator support, and iv) automated and autonomous material flow. The paper describes and visualize how currently available digital technologies can be applied in the yard logistics context, to achieve those four main features. The concept may be used as inspiration for moving towards the next generation of yard logistics. The paper also addresses qualitatively the potential effects of digitalized yard logistics on yard logistics performance. In this way, the paper may serve as a starting point for more advanced and specific developments, as well as possible realizations, of digitalized yard logistics systems.

Keywords: Yards, engineer-to-order, logistics, digitalization, Industry 4.0.

1 Introduction

Yard operations can be classified as engineer-to-order (ETO) manufacturing operations. With the ETO manufacturing approach, some design and engineering as well as purchasing and physical production are performed after a customer order has been contracted (Gosling & Naim, 2009). ETO manufacturing is sometimes called one-of-a-kind manufacturing, as products that are designed and engineered based on a specific customer order are often the only ones of their kind. The implications for the manufacturer, or the yard, is that, since every product is designed and engineered based on the customer's requirements, it will never make a product in exactly the same way again. The yard, in this case, is also a logistics hub receiving materials from a large number of suppliers, with the challenging task of efficiently coordinating and managing these materials to have them processed and installed on the end product. This has major implications for internal logistics and creates a dynamic, uncertain, and complex manufacturing environment (Bertrand & Muntslag, 1993). These characteristics distinguish this type of manufacturing environment from more repetitive manufacturing environments. The need for coordination of material and information flows is critical (Mello et al., 2017), and tailored approaches are required for effective and efficient management of manufacturing operations (Adrodegari et al., 2015). However, there is a lack of logistics solutions that fit the ETO context (Zennaro et al., 2019).

Research on Industry 4.0 related to the ETO context has received growing attention, although it is still in an early phase (Cannas & Gosling, 2021; Zennaro et al., 2019). Moreover, research on the application of Industry 4.0 to manufacturing logistics indicates that new digital technologies are easier to apply in companies in which the repetitiveness is high (Strandhagen et al., 2017). For less repetitive environments, such as yards and other types of ETO environments, application of digital technologies seems more difficult. The high complexity, uncertainty, and dynamism created by the characteristics of the ETO environment are believed to be key factors affecting the applicability of digital technologies. On the other hand, the potential for improvement if digital technologies are successfully adapted and applied should be correspondingly large, as complexity and dynamism are exactly what digitalization is expected to manage more efficiently. Accordingly, digitalization is expected to be a promising approach and enabler of improved yard logistics performance. However, it is still not clear how digital technologies can and should be applied in yard logistics.

There is currently an emerging research stream on Industry 4.0 in ETO (Cannas & Gosling, 2021), and research on the application of Industry 4.0 technologies in the specific context of ETO manufacturing is seen as a central part of future research in the field (Zennaro et al., 2019). Nevertheless, existing research has considered only a limited number of specific, technological applications for specific areas or processes in yard operations. The digitalization of yard logistics is still at a superficial level, and more empirically based research is required to identify the most relevant application areas. Therefore, this paper will investigate how digital technologies can be adapted and applied to move towards the next generation of yard logistics.

2 Related work

Willner et al. (2016) conceptualizes four archetypes of ETO products: complex, basic, repeatable, and non-competitive ETO. These are determined by two dimensions: annual units sold (average number of units sold over a period of n years) and engineering complexity (engineering hours per the average of annual units sold). Complex ETO products are produced in lower volumes and with a higher engineering complexity, for example, ships, oil platforms, and nuclear plants (Willner et al., 2016). Yard operations fall within this ETO category, and is also characterized by large-sized, complex products with deep product structures, manufacturing carried out as large projects in fixed position layouts, a high level of customization, and highly integrated and overlapping processes.

Research have highlighted a lack of advancements of digitalization in ETO in general (Zennaro et al., 2019), and this lack seems to apply also to yard logistics specifically. There are a few articles addressing various aspects of digitalization of shipbuilding in general. They are predominantly exploring the broad outlines of digitalization of the shipbuilding industry (Beifert et al., 2018; Blanco-Novoa et al., 2018; Fernández-Caramés et al., 2018; Jha, 2016; Joe & Chang, 2017; Munín-Doce et al., 2020; Para-González & Mascaraque-Ramírez, 2020; Ramirez-Peña et al., 2019, 2020; Sanchez-Gonzalez et al., 2019; Stanić et al., 2018), with only a few investigating the application of digital technologies at yards. Nevertheless, there have been efforts to conceptualize digitalization in yard operations, and Strandhagen et al. (2019) outlined a set of four required features of a digitalized yard logistics system, which this paper aims to build on:

- Seamless, digitalized information flow
- Identification and interconnectivity of objects
- Digitalized operator support
- Automated and autonomous material flow

In Strandhagen et al. (2019), these four features were suggested to address four corresponding logistics challenges that characterize the yard logistics system: IT system integration and sharing of up-to-date information; localization of materials, equipment and tools; complex and information demanding work for operators; and manual material handling and irregular and disrupted flows.

3 Research approach

The research in this paper followed a qualitative approach, which is particularly useful when seeking to understand real-world situations and their patterns and structural features (Flick et al., 2004). Accordingly, the research targeted qualitative data, which can be powerful for both discovering and exploring new ideas (Miles et al., 2014). In order to understand the context, needs and requirements of yard logistics—as well as to map the current state of digitalization—a multiple case study was used as the main element of our research approach, based on the steps and principles for case research (Yin, 2018). Due to Covid-19 travel restrictions, only Norwegian yards were considered for the study. Fourteen Norwegian yards were identified as potential cases fulfilling the inclusion requirements—manufacturing sites with operations that could be classified as complex ETO and yard operations—and ultimately, eight yards were visited and included in the study. Data were collected from interviews, direct observations, and existing documentation, and a case description for each yard was developed and organized. Through this process, key insights from each case yard were generated, and commonalities and differences between the yards emerged, allowing the unique patterns of each case to be observed. Table 1 gives an overview of the cases involved in the study, with a short description of the products built at the yard and the yard size in terms of its total area and typical number of operators.

Table 1: Overview of the cases involved in the study.

Case	Primary activity	Yard size (m^2)	# of yard operators
A	Oil platforms and modules, offshore wind platforms	234 000	1200
B	Floating offshore platforms, platform topsides, onshore facilities for oil and gas processing, offshore wind platforms	250 000	800
C	Steel jackets for offshore platforms, offshore wind jackets, subsea structures	650 000	482
D	Smaller service operations on a range of different types of ships	20 000	50
E	Refurbishments, rebuilds, repairs, upgrades and smaller service operations on different types of ships, and some outfitting operation.	91 000	500
F	Outfitting and service operations on ships for offshore, fishery and other types of specialised vessels	30 000	142
G	Outfitting operations on advanced and customised ships for certain markets	75 000	300
H	Outfitting operations on advanced and customised ships for certain markets	20 500	90

In the extension of the case research, a concept development activity was carried out. This concept development activity is inspired by the design science research (DSR) method, which aims at developing generic knowledge from real field problems, with generic designs as the core research product (van Aken et al., 2016). The research product of DSR can eventually take the form of a construct, a model, a method, or an instantiation (Hevner et al., 2004). In this paper, the concept development activity utilized the previously described case studies, which explicate the challenges of yard logistics and identify the requirements for digitalized yard logistics. Accordingly, the case studies were the contextual or environmental foundation for the concept development, providing an understanding of the particular field problems of yard logistics. Similar as a design science activity, the concept development activity was connected to the scientific knowledge base through being built on reviews of applicable digital technologies. These informed and guided the concept development. Accordingly, with an understanding of the yard logistics context through case studies, and a connection to the state of the art of digitalization, a concept for digitalized yard logistics could be developed.

4 Current state of digitalization of yard logistics

To outline future steps in yard logistics digitalization and identify feasible solutions, an overview of the current state of digitalization in yard logistics is necessary. This was explored through a multiple case study, structured by four key aspects: technology implementation, strategic emphasis on digitalization, resources and initiatives, and utilization of IT systems. These aspects were combined to evaluate the current level of digitalization at each case yard, as shown in Table 2.

The mapping reveals that yard logistics still has a long way to go to achieve complete digitalization. While some yards belong to digitalized companies, overall, the implementation of digital solutions in yard logistics is limited. Only a few yards have implemented relevant technologies, including digital devices and small-scale AR/VR solutions, which show promise. Other yards are conducting tests and investigations of potential technologies.

Regarding IT systems, some yards have comprehensive, self-developed logistics systems with substantial data, but they lack full integration with other systems, resulting in manual administrative tasks. Most yards operate without any IT system for yard logistics, relying on analog formats and extracting information from ERP systems.

The mapping of digitalization strategies concerns whether the digitalization is an explicit part of the strategy of the company operating the yard—and whether this is extended to yard logistics. Only four out of eight yards have digitalization as part of their company strategy, indicating a lack of focus on yard logistics digitalization. Moreover, the lack of resources dedicated to working on digitalization initiatives seen in most of the yards may impede advancements.

Among the selected cases, fabrication yards show the highest level of digitalization in yard logistics. This could be attributed to factors such as the size of the operating companies, as larger enterprises tend to have higher digitalization levels (Buer et al., 2020). Another possible factor relates to the sectors the yards serve. Offshore construction typically has higher profit margins than shipbuilding and is, therefore, likely to have more resources available for company development initiatives such as digitalization efforts.

The empirical data clearly indicates the existence of significant barriers in terms of implementation costs and obtaining top management approval, as well as challenges in assessing the potential benefits of digitalization initiatives. Many yards struggle with the financial burden and justification of such investments. Interviewees also highlighted the difficulty of finding solutions suitable for the demanding physical environment of yards, characterized by large unprotected outdoor areas and metallic objects that pose challenges for certain digital technologies like localization systems. Resistance to change emerges as another potential barrier. While not directly observed, statements from interviewees suggest that operators may exhibit reluctance to embrace new technologies in their daily work during future implementations. However, this reluctance could be attributed to the immaturity or unsuitability of the technologies.

Table 2: Current state of digitalization in yard logistics at the case yards.

Case yard	Technology implementation	Digitalization strategy	Digitalization resources and initiatives	IT system use and integration of systems	*Digitalization level**
A	Wi-Fi throughout the yard, tablets for work management, AR has been tested in assembly, pilot projects on materials tracking.	Digitalization is part of the company strategy. Pilot projects and proof of concept studies.	Dedicated resources and internal initiatives working on digitalization.	Several IT systems supporting yard logistics, but only partly integrated. Information made available for operators in digital format. Some digital connection to the yard floor.	***Medium***
B	App for work management, development of digital twin in progress, investigating camera recognition for materials identification.	Digitalization is part of the company strategy. Pilot projects and proof of concept studies.	Digitalization is a focus area, conducted mappings/studies on digitalization and how it can be applied in the company.	Several IT systems supporting yard logistics, but only partly integrated. Information made available for operators in digital format. Some digital connection to the yard floor.	***Medium***
C	App for work management.	Digitalization is part of the company strategy. Pilot projects and proof of concept studies.	Digitalization is a focus area, conducted mappings/studies on digitalization and how it can be applied in the company.	Several IT systems supporting yard logistics, but only partly integrated. Information made available for operators in digital format. Some digital connection to the yard floor.	***Medium-***
D	No implemented digital technologies, informally introduced to AR/VR for the inspection of ships.	Digitalization is not part of the company strategy.	No specific resources for digitalization.	Only basic ERP functionality, with limited to no yard logistics support. Many manual administrative tasks, manual registration and writing of lists. No digital connection to the yard floor.	***Very low***
E	Tablets for work management on a few previous projects	Digitalization not part of the company strategy.	No specific resources for digitalization.	Basic ERP functionality, IT system supporting basic procurement tasks. Manual administrative tasks. No digital connection to the yard floor.	***Low***
F	No implemented technologies.	No strategic emphasis on digitalization, although they recognize the need for digitalization.	No specific resources for digitalization, and they are involved in research project applications on the topic.	IT systems for specific applications, but not integrated to support yard logistics. Digital information printed on paper before distribution to operators. Many administrative tasks are performed manually, with manual registration and writing of lists—and manual checks of them. No digital connection to the yard floor.	***Very low***

Case yard	Technology implementation	Digitalization strategy	Digitalization resources and initiatives	IT system use and integration of systems	*Digitalization level**
G	No implemented technologies. Investigating the potential to use AR in research projects.	Digitalization is somewhat part of the company strategy.	No designated positions for digitalization. Some smaller digitalization initiatives and participation in research projects.	Partly integrated structure of IT systems, to some degree supporting yard logistics. Digital information printed on paper before distribution to operators. No digital connection to the yard floor.	***Medium-***
H	No particular technologies implemented.	No strategic emphasis on digitalization, although they recognize the need for digitalization.	No specific resources for digitalization.	IT systems for specific applications, but not integrated to support yard logistics. Digital information printed on paper before distribution to operators. Partly used item tagging system for identification of materials, however not automated and requires manual scanning of tags attached to the materials. No digital connection to the yard floor.	***Low***

*Digitalization level has been assessed using the following ordinal scale: Very low, low, medium-, medium, medium+, high, very high.

5 Towards a concept for digitalized yard logistics

The concept is based on technologies that are available today and aimed towards realistic implementations of digital technologies in an industrial context, i.e., what it could look like in the foreseeable future). Strandhagen et al. (2019) identified four required features of a digitalized yard logistics system, and in the concept development process these are transformed to the four elements of the concept for digitalized yard logistics. The four elements are shown in and described in detail in the following paragraphs.

5.1 Seamless, digitalized information flow

Efficient yard logistics relies on efficient distribution of the information that is required to execute yard logistics activities and make decisions. Especially, the close interaction between non-physical processes, such as engineering and project management, and production requires integrated IT systems for the efficient control and execution of the yard logistics activities. There is a need for a seamless, digitalized information flow, where all subsystems are integrated. Information should flow from higher-level IT systems to the production floor whenever needed, providing access to real-time information. The general purpose of such seamless, digitalized information flow is to make the relevant information available for the executing actors. Key aspects of seamless, digitalized information flow in yard logistics include:

- The supervisors receive up-to-date, digitalized information from higher-level systems, such as ERP and project management systems, regarding the next work packages to complete, operator availability, material status, and resource availability (facilities, production halls/areas, transportation resources) required for the distribution of work packages.
- Assigning a work package (by a supervisor in a control system) could potentially activate the required actions (the information is sent) to pick and bring the material to the place of use (e.g., booking transportation and giving information to the transport equipment that will perform the transportation) and activate the provision of information (work package description) to the operators the work package was assigned to.
- The transportation operators (or automated and autonomous transportation equipment), upon being assigned to an internal transportation job, receive information regarding the correct items to pick, where to pick them from, and where to deliver them.
- The production operators, upon being assigned to a work package, receive the information required to execute the job, such as drawings, work instructions, and about which items (both material and equipment) are to be used and their locations in the yard.

- Warehouse operators receive the required information upon receipt of incoming materials to the yard and upon receiving internal material requisitions for internal supplies.
- Progress reports from operations are automatically and instantly sent in a digital format to the relevant parts of the yard organization.

5.2 Identification and interconnectivity of objects

It is challenging to gain an overview of all the materials, equipment, and tools needed to perform yard logistics activities. IoT, with objects equipped with sensors and actuators to enable storing and sharing of information, have the potential to mitigate these challenges by providing identification and interconnectivity. Identifying and interconnecting objects in a facility would enable a highly integrated way of managing operations. The general purpose of identification and interconnectivity is to provide a complete overview of the yard's materials, equipment, and tools. We consider two possible approaches to real-time location of objects:

- Physical object tagging of:
  - Materials—transmitting information about their location, status, etc. This information should then be available for the relevant logistics systems (e.g., for picking the correct items from storage, finding them without having to search).
  - Transportation resources—enabling the networking of all transportation resources, potentially improving the process of selecting resources for different transportation jobs (e.g., booking of an available and close resource for a transportation job).
  - Other equipment used by operators.
- Identification of objects through vision/recognition technology
  - Cameras mounted on transportation equipment, building structures, operators' helmets, drones, or other suitable places, to scan objects in order to identify them, update location, view status, etc.
  - The information acquired is transmitted to relevant logistics systems or used directly by the transportation equipment, operator, or drone for its current task (e.g., to pick the object it is looking for).

Irrespective of the technical solution, the ability to identify and interconnect objects in the yard will present great opportunities regarding the management of the objects.

5.3 Digitalized operator support

In yard logistics, it is critical for the operators to receive timely and correct information about the tasks to be performed, such as, drawings and work instructions. Digitalized yard logistics should therefore include digitalized operator support where operators have access to digital tools, such as smartphones, tablets, or similar, to view work instruction, drawings etc. In this way, digital technologies are utilized to provide enhanced support for operators, ensuring rapid and easy access to information. Key aspects of digitalized operator support include:

- Work package descriptions available electronically on handheld devices, such as tablets or smartphones.
- AR or VR solutions to support various tasks, including:
- Warehouse operations such as picking, where AR-based information can provide enhanced information on where to find the correct item in the warehouse.
- Outfitting jobs, where AR solutions can be used to visualize the operators' tasks. For instance, the specific item to be installed on a ship can be projected—through AR-glasses—showing the operator where it is to be installed.
- Digitalized solutions for operators and supervisors to report progress. This should make the important activity of progress reporting as convenient as possible.

5.4 Automated and autonomous material flow

With the comprehensive material flow at yards, great potential lies in making material flow more efficiently. In yard logistics, digital technologies can bring autonomy and automation to the physical flow of materials. Components, parts, assemblies, tools, equipment, and other objects could then be transported more efficiently and with less human intervention. Key aspects of automated and autonomous material flow in yard logistics include:

- Automatic guided vehicles (AGVs), autonomous mobile robots (AMRs), and collaborative robots (COBOTS) for material handling and performing logistics operations in warehouses.
- Automated and possibly autonomous conveyors, cranes, and vehicles (self-elevating transporters, multiwheelers, etc.) for transporting heavy or high-volume materials around the yard
- AMRs (vehicles or drones) for transporting light, low-volume materials around the yard
- Automatic storage systems, such as Pater Noster material handling systems, for efficient storage of smaller sized materials.

5.5 Concept features and visualization

Together, these four elements form a holistic concept for digitalized yard logistics. Fig. 1 shows ten features the concept can bring to yard logistics:

1. Digital product information from design and engineering to supervisors and operators.
2. Cloud-based information management for yard logistics information, including product information from design and engineering, progress information from production, inventory information from warehouse, work package information, etc.
3. Supervisors equipped with digital devices with information relevant for work management.

4. Digital assignment of work packages to operators, along with work package descriptions and product information made available for operators on digital devices.
5. Interconnection of transportation equipment, receiving information on new jobs, such as, when and where to pick up which materials and where to deliver them.
6. Identification and location of objects through physical object tagging or vision technology.
7. Items in warehouses identifiable through technology and connected to work packages based on availability and needs.
8. Autonomous material handling in warehouses and other storage areas.
9. Operators performing outfitting operations equipped with AR devices that provide support during outfitting.
10. Yard equipment interconnected and digitally assigned to jobs, with digital communication of status.

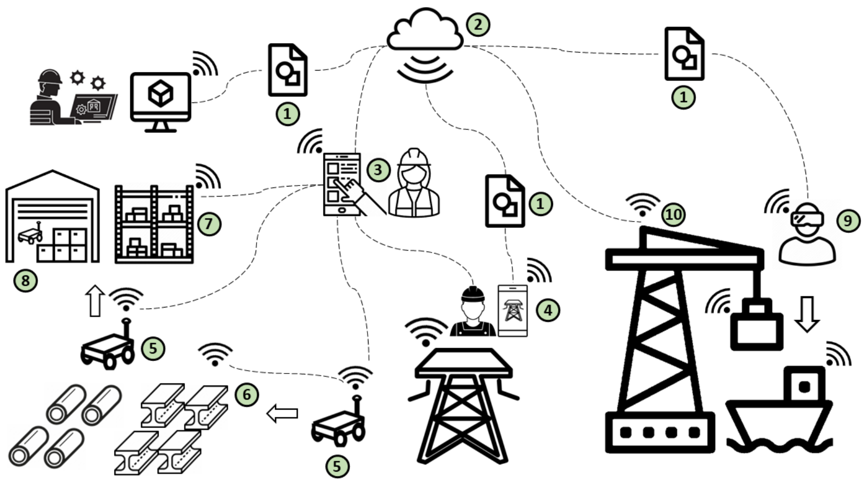

Fig. 1. Visualization of the ten features of the concept for digitalized yard logistics.

The concept has been developed on the basis of technologies that are available today, albeit not currently commonplace at yards. Accordingly, there are several technology requirements that are necessary for the concept to be realized, which include the following:

- AR devices. There are several types of AR devices available today that may suit a yard logistics context. A physical device, in the form of a smartphone, tablet, headset or glasses, equipped with the required hardware and software to run AR applications is necessary.
- Identification technology system, either based on physical object tagging, for example a RFID system, or based on vision/recognition technology. This requires both hardware and software.

- Autonomous vehicles and automation technology for autonomous and automated material handling.
- Networking technology to transmit information wirelessly between systems, objects, etc.
- Software for logistics control, including the control logic.

For the successful realization of such a heavily technology-based concept, the human aspect of yard operations must be considered and addressed. Certain parts of the concept build on operators' adoption of new technologies, such as wearables and other digital devices, in their daily tasks. Accordingly, this may require changes in the way the people involved in yard logistics work. For the described concept, adaptation is needed with regard to the use of AR devices, such as glasses and headsets, interacting with digital interfaces (e.g., smartphones and tablets), and becoming accustomed to autonomous vehicles operating in the yard.

Another important issue for the realization of such a concept relates to the investment requirements. The mapping of the current state of digitalization indicates that there are potential barriers related to the investment costs. With the high uncertainty in the yards' current situations, it is associated with great risk to make any investments if they cannot be covered through current projects. Moreover, the novelty of a technology may make it difficult to estimate the potential benefits.

Although the economic benefits may not be easily quantified, it is possible to qualitatively discuss the potential effects of digitalization on yard logistics performance. Potential effects of digitalization on yard logistics performance include:

- Digital information flow enhances internal order processing involving production and warehouse
- Reduced put away cycle times for incoming materials due to rapidly, digitally available information on materials and their destined warehouse locations
- Improved information quality due to enhanced, digital information exchange
- More rapid location of the materials to be picked
- Less time spent locating materials with enhanced localization through networking of objects
- Enhanced transport efficiency through better overview of items, facilities, and equipment.
- Better overview for operators, reducing the unnecessary time spent walking and searching for items
- Increased productivity of operators, e.g., though solutions to assist in material picking, reducing picking time
- Increased productivity of operators, e.g., through digitally available up-to-date work package descriptions
- More efficient warehouse operations with automated solutions
- More efficient internal transportation through automated transportation
- Reduced put away cycle time due to automated material handling solutions in warehouse
- Reduced order picking cycle times due to automated warehouse solutions

6 Conclusions

The paper has proposed a concept for digitalized yard logistics. The development of a concept for digitalized yard logistics is an effort to extend the general conceptualizations of digitalization (Dalenogare et al., 2018; Fatorachian & Kazemi, 2020; Frank et al., 2019) to the yard logistics context. The existing literature includes some partly related conceptual descriptions, where Ang et al. (2017) present a general framework for digitalized ship design and engineering, production, and operation, Stanić et al. (2018) describe "shipbuilding 4.0"—a general concept regarding the digitalization of shipbuilding, including shipyards, shipowner, suppliers, and other actors in the shipbuilding supply chain, and Woo & Oh (2018) describe "digital shipbuilding"—a computer-based production management concept for modeling and simulating stages of the shipbuilding process. Accordingly, the concept described in this paper stands out because it addresses the digitalization of yard logistics—a narrower scope than existing shipbuilding concepts, and a wider scope than concepts focusing on modeling and simulating shipbuilding. This can make it more useful to practitioners in their effort to apply digital technologies in yard logistics. The concept may serve as a starting point for more advanced and specific developments as well as possible realizations of digitalized yard logistics systems, which should be the aim of further work. Thus, the paper contributes to expanding the field of digitalization of manufacturing and logistics to the context of yard logistics and yard industries. This enhances the general understanding and knowledge of the potential impacts of digitalization and widens the solution space for solving yard logistics challenges.

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