

The significance of digital waste in the automation of Lean practices

Jamila Alieva^a and Daryl Powell^{b,c} 

^aFaculty of Engineering and the Environment, University of Gävle, Gävle, Sweden; ^bSINTEF Manufacturing AS, Horten, Norway; ^cNorwegian University of Science and Technology, Trondheim, Norway

ABSTRACT

Lean manufacturing has experienced massive changes under the influence of Industry 4.0 as the automation of lean practices has become common among manufacturing companies in many countries and across different industries. Automating lean practices promises several opportunities for growth and competitiveness. One of the acknowledged key advantages of lean automation has been the significant reduction of waste. Meanwhile, there is also discussion of a new form of waste: *digital waste*. However, do companies consider digital waste a part of production waste? It is also unclear if the automation of lean practices is a trigger for digital waste with a negative impact on value creation. This paper aims to investigate companies with automated lean practices and the digital waste generated by these practices. The research is based on three case studies of manufacturing companies based in Sweden. The originality of the study identifies and highlights the significance of various forms of digital waste, which is of academic and practical relevance. The study indicates that there is digital waste in supplier-related lean practice—automated JIT delivery—specifically in product-oriented and service-oriented technologies. There is digital waste in internally related lean practice—automated set-up—specifically in process-oriented technologies. Finally, there is digital waste in customer-related lean practice—digitally involved customers—in product-, service-, and process-oriented technologies.

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1. Introduction

Industry 4.0 is pushing the automation of lean practices (Amjad et al. 2020; Jasperneite et al. 2020; Shahin et al. 2020; Tortorella et al. 2020, 2021). The study of manufacturing process automation has increased spectacularly within the last few years, corresponding to the expected improvements in production, quality, and safety (Frontoni et al. 2020; Lazai et al. 2020; Pantano et al. 2020). Substantial reduction of waste under the control of technologies is one of the key benefits attracting manufacturing practitioners (Ejsmont et al. 2020; Purushothaman et al. 2020; Tortorella et al. 2020, 2021). Lean automation leads to manufacturing transformation with cheaper, smarter, and more adaptable processes (Tilley 2017). ‘Industrial IT and automation have annual sales of over SEK 70 billion in Sweden, of which the Stockholm region accounts for 70 percent’ (Stockholm Business Region, 2013). The Norwegian Research Council initiated the project to promote small and medium enterprise (SME) cooperation and flexibility by automating the manufacturing processes within the Norwegian SMEs to help them stay competitive

globally (Wadhwa, 2012). Two definitions of lean automation are the networking of equipment and people for rapid communication with the aid of digitalization (Palange & Dhattrak, 2021) and the establishment of the platform and connective mechanisms to utilize data analytics from the real world (Soufhwee et al. 2021). Lean automation is also associated with a disruptive digital technology from Industry 4.0. It emphasizes the importance of adopting levels of technologies based on the performance of the companies, as well as how advanced the adoption of their lean practices is (Tortorella et al. 2021). There is a positive correlation between Industry 4.0 technologies and lean practices with a high potential to overcome traditional barriers and challenges when using the lean management approach (Buer et al. 2020; Tortorella et al. 2020).

Indeed, while the potential benefits that adoption of lean automation can bring are discussed by researchers (Amjad et al. 2020; Pantano et al. 2020; Purushothaman et al. 2020; Shahin et al. 2020; Tortorella et al. 2020, 2021), studies investigating potential risks associated with automating lean practices are lacking. The topic of digital waste is relatively new in the field of lean

manufacturing (Alieva & Haartman, 2020; Romero et al. 2019a). We need a deeper discussion of digital waste in the context of lean automation.

Tortorella et al. (2020, 2021) discussed a variety of automated lean practices using quantitative methodologies. This qualitative study is limited to three lean practices only—JIT delivery (supplier oriented), low set-up (internally related), involved customers (customer oriented).

2. Theoretical background, framework, and research question

2.1. Industry 4.0 and technology

2.1.1. Process-oriented technology

Among several resources considered essential for Industry 4.0 adoption, production systems (product and process traceability), and big data analytics (big data processing capability) were recognized as being key (Bag et al. 2021). Production data employing servers, sensors, and cloud computing have impacted data exchange procedures that have become more complex. Lean manufacturing and decision making are likely to improve on the process level with the integration of data analytics and the Internet of Things (IoT) (Soufhwee et al. 2021). The increased amount of production data requires autonomous monitoring, control, and optimization of value creation processes through the lean-data approach. There is need for new, process-based, technological solutions, such as decentralized sensor systems dealing with growing volumes of data at close to real time with an accuracy of more than 95% (Küfnera et al. 2021; Schmidt et al. 2020).

2.1.2. Product-oriented technology

Industry 4.0 offers technologies for product improvement and innovation of manufacturing operations. It is important not to dismiss the focus on smart products through simulation, additive manufacturing, and augmented reality (Powell et al. 2018). One example of a smart product is 3D printing. It appears early in a product's life cycle, and it is the foundation for building multifunctional structures as smart products with integrated sensors in the manufacturing process chain (Lenz et al. 2020). Big data analytics, additive manufacturing, and sustainable smart manufacturing technologies are beneficial to manufacturing enterprises to make better decisions for the beginning-of-life stage of the product life cycle (Majeed et al. 2021; Yang et al. 2021).

2.1.3. Service-oriented technology

The lean method can integrate new technologies and allow better support of continuous improvement in the

world of increasing product complexity. Smart products are connected to sensors and able to store a large amount of data, self-process, and communicate with industrial systems throughout their in-service life (Saxby et al. 2019). Data prediction has increased in popularity throughout the manufacturing sector for the planning and control forecasting that spans the entire life cycle of a product. Service-oriented and cloud-based technologies are implemented throughout the supply chain to ensure secure data access for testing, prototyping, and factory optimization (Caiado et al. 2021). Additive manufacturing, augmented reality, and 3D simulation of product/service development and production processes are promising technologies in the Industry 4.0 environment. They disruptively change supply chains, business models, and business processes through interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity (Marcucci et al. 2021). A study at an auto-parts manufacturing firm (Amjad et al. 2020) discovered the combination of lean manufacturing and Industry 4.0, where the positive influence of smart production control and cyber-physical systems optimized lead times, non-value-added time, and value-added time by 25.60%, 56.20% and 24.68%, respectively.

2.2. Lean practices

2.2.1. Internally related lean practices

Production scheduling involves the continuous flow of processes that provide support for achieving production of standardized products. Control of product flow forecasting approaches and monitoring take time (Yadav et al. 2020). The synergy between quality and lean practices leads to improved flow processes (Onofrei et al. 2020). For increased productivity and a better working environment for the operator, a one-piece flow technique is used to manufacture product components. The flow describes the sequence of transient activities in a process within a single stage of production within a certain time frame. It increases the number of products through the process steps simultaneously (Apafaian et al. 2020). Identification of techniques for setup time reduction is listed as one of the biggest challenges faced by automobile component manufacturing firms while implementing lean practices (Sahoo, 2020). Some of the reasons for increased setup time are the underutilization of creel, lack of tools, and improper scheduling (Prasad et al. 2020). The single-minute exchange of dies is a lean technique that involves separation and conversion of internal setup operations into external operations. The goal of the

technique is to achieve a setup time of less than ten minutes (Gomero-Campos et al. 2020). Advanced manufacturing is moving toward mass customization, where long setup times between variants are unacceptable within a priority of competitiveness through process technology (Omoush, 2020).

2.2.2. Supplier-related lean practices

Supplier management was highlighted as one of the most important social factors for successful lean implementations along with employee involvement, internal technical practices, and customer management. It requires long-term relations with suppliers; feedback on quality and delivery performance; close contact with suppliers, especially senior management on the most important issues related to suppliers' involvement (Malik & Abdallah, 2020). The just-in-time (JIT) lean purchasing approach is very convenient for long-term relations with suppliers. It can be optimized in three dimensions: management, financial, and technological. The technological dimension improvement expects partners to be more willing to share and give access to technology. It can also motivate partners to participate in product design based on knowledge and commitment from the other partner. Supplier involvement in design could lead to improved quality and reduced time to market (Taghipour et al. 2020). Supplier integration is positively associated with the speed of new product introduction, but it does not support lean practices for operational performance indicators. Lean practices are positively associated with operational performance indicators, but not with delivery (Bento et al. 2019).

2.2.3. Customer-related lean practices

Companies widely count on customer involvement to help with issues such as quality standards, facilitating customer participation in product development processes, and technical assistance (Bento & Tontini, 2019). Customer focus was recognized as one of the key successes (external) factors for lean manufacturing along with government intervention (Alefari et al. 2020). A customer focus addresses emerging customer requirements and expectations, manages customer relationships, and defines customer satisfaction (Bento & Tontini, 2018). The relationship between lean and customer-focused performance is mediated by process improvement. Being lean relates positively to having a customer-focused performance in an environment where customer effectiveness is valued (van Assen, 2021). Indeed, the level of lean maturity is related to the level of customer focus, especially regarding external customer involvement in product development

(Bento & Tontini 2018). Attention to customer satisfaction, customer relationships, and customer involvement are discussed in the context of indicators of soft lean practices and do have an impact on quality. Among the hard lean practices, total quality management is an indicator of the delivery to customers (Sahoo 2019).

2.3. Lean, waste, and industry 4.0

The elimination of waste (*muda*) was discussed in 1990 in *The Machine that Changed the World* (Womack & Jones 1990) through a five-stage process: specification of value, identification of value stream, creation of flow, pulling the product as needed, and aiming for perfection. Often, lean production was primarily associated with elimination of waste as excess inventory or excess capacity to impact the variability in supply, processing time, or demand (Shah & Ward 2007).

In the digital era, a new way of integrating lean thinking with digital technologies—sensors, CPS, IoT, and social networks—has arisen (Cattaneo et al. 2007). Industry 4.0 and lean methodology have a strong correlation due to sharing the similar priorities of waste reduction and efficiency gains (Pavlovic et al. 2020). The new concept of digital lean manufacturing involves human capabilities and strategic digital technologies, as well as quality planning, control, and improvement (Romero et al. 2019a). Industry 4.0 should not be treated as a single technology. Instead, it integrates product, process, and system levels to reveal its potential for advance manufacturing competitiveness (Enyoghasi & Badurdeen, 2021).

Manufacturers need to systematically combine lean thinking and practices with advanced Industry 4.0 technologies to build a competitive advantage in the digital era; at the same time, they need to implement a successful lean transformation through improved performance and capability. By applying 'lean and learn' as a lens for strategic lean practice automation, learning can play a vital role in the continuous improvement process (Bäckstrand and Powell 2021). Learning in combination with an automation approach would improve the efficiency of manufacturing processes and develop the workforce skills to adopt advanced automation solutions (Bäckstrand and Powell 2021; Romero et al. 2019b; Romero et al. 2019c; Solheim & Powell, 2020).

2.3.1. Digital waste

Very few authors openly discuss the digital waste existence, or the challenges associated with it (Alieva & Haartman, 2020; Romero et al. 2018). The definition of digital waste is at the earliest stage of its development,

which opens the research gap on one hand, yet creates a challenge to formulate the concept and have a quality discussion reflecting on existing definitions objectively and efficiently. In considering digital waste, there is an acute awareness of the growing volumes of data in close to real time. For this reason, a 'lean data approach' was developed for information aggregation to derive machine-based knowledge (Küfner et al. 2021). Digital waste has been discussed as buffer waste in the context of the cyber-physical production system from four interdependent perspectives: physical to physical, physical to digital, digital to physical, and digital to digital (Romero et al. 2019a). It has also been defined as any non-value-adding digital activity to women/men, materials, machines, methods, measurements and it can appear due to lost digital opportunities and/or overuse of the digital capabilities of new digital manufacturing technologies (Romero et al. 2018). **In this paper, we follow the definition of digital waste as uncollected, unprocessed, or misinterpreted data in the production process (Alieva & Haartman, 2020).**

2.4. Theoretical framework, research objective and research question

A summary of the theory can be seen in Figure 1.

The objective of the research is to explore the case of digital waste resulting from automated lean practices. The study aims to respond the following research question:

RQ: How does the automation of lean practices (supplier-related, internally related, customer-related) contribute towards or eliminate digital waste?

3. Research methodology

Exploratory research through multiple case studies was selected as the method (Barratt et al. 2011; Childe 2011). The scope of the study aimed at discovering the potential

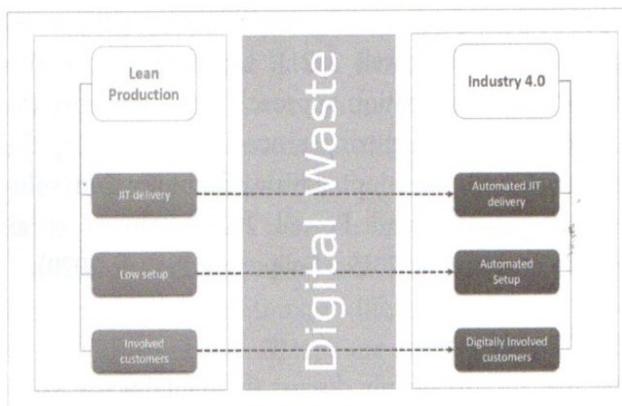


Figure 1. Theoretical framework of this study. Text: Illustration of how digital waste can become an outcome of Automation of lean practices (JIT delivery, low setup, and involved customers).

existence of digital waste in automated lean practices. The study allows the creation of knowledge for both practitioners and academicians who are experiencing or investigating digital adoption in manufacturing (Jack, 1998; McCutcheon & Meredith, 1993). The cases were selected from among Swedish manufacturing companies based in the Gävle region. A preliminary list of companies was created based on an internet search. Companies were contacted over the phone, and each was investigated to ensure that the selection criteria were met: the adoption of lean practices, automated processes, and a willingness and openness to participate in the research. The territorial limitation was kept to Sweden. Pandemic adherence restricted travel and the ability to observe the factories, as well as limited the working capacity of factories themselves, including production. Some manufacturers shut down their factories in observance of the pandemic quarantine, which further limited the number of cases available for the study to three.

The factory is a unit of analysis that corresponds to the adoption of automated lean practices (Barratt et al. 2011; Voss et al. 2002). In one way, the cases are homogeneous, since all three companies are in Sweden. On the other hand, the approach of each of the selected cases is heterogeneous since all three cases produce very different type of products for different industries. Moreover, two companies are SMEs, while the last company is much bigger in size by comparison. The approaches' heterogeneity was chosen intentionally to observe the differences between bigger and smaller companies. Larger companies have more resources in the adoption of new technologies and the automation of lean practices. By contrast, smaller companies tend to learn from bigger companies and are motivated by market competition or by being a part of the same supply chain.

Data was collected through semi structured interviews (Chide, 2011; Voss et al. 2002). Table 1 shows a summary of interviews. In the face-to-face interviews, notes were taken during the interview. In zoom meetings, interviews were recorded with the permission of interviewee. After the interviews, a summary of notes was transcribed, sorted, and coded (Voss et al. 2002). The coding phase involved a content analysis to define the relations between different answers. Triangularity

Table 1. Interviews summary.

Company	Type	Interviews/Observations	Length	Format
Company A	SME	Plant manager	2 h	Face-to-face
		Observation	1 h	Factory
Company B	SME	Plant manager	2 h	Face-to-face
		Observation	1 h	Factory
Company C	Corporation	Strategic purchaser	1 h	Zoom
		Production engineer	1 h	Zoom
		Customer service manager	1 h	Zoom

was reached through the online available reports about the companies, videos about companies, and interview notes (McCutcheon & Meredith, 1993; Voss et al. 2002). The coding process was conducted manually for the purpose of intercode reliability (Duriau et al. 2007). The interview model was divided into three sections—automated JIT delivery, automated set-up, digitally involved customers. Each section had three sub-sections—product-oriented, service-oriented, and process-oriented technologies. Appendix is a summary of the interview questions. Observations were conducted in Company A and Company B with a shop-floor tour, analysis of documents and paperwork procedures from the order formulation till order submission. However, observations in Company C were not possible due to pandemic restrictions, which is considered a limitation of the selected research method.

3.1. Case studies

3.1.1. Case A

Company A, based in Gävle, Sweden, has had 20 years of experience in customized switchboard production for private companies. There are 22 people employed by the company, who have an average age of 40 years. Approximately 95% of the employees are males. Each switchboard is assembled by one employee in approximately 24 hours at one working desk. Consequently, there is no need for an automated setup or smart flow due to the nature and simplicity of the tasks. Daily interactions with customers are time-consuming and often require middle management involvement to negotiate delivery, price discounts, or order specifications. All the information is saved on the company's drive and is not sorted or processed systematically for continuous improvements. However, Company A has very automated relations with their suppliers. About 60% of orders are packed by robots with zero human interaction. In cases when the order formulation is done by robot, it is possible to receive incorrect items inside the box. The items are accompanied by packing slips. In the case of a robot mistake, the description on paper is correct (matching the order), but the items inside the box are wrong.

3.1.2. Case B

Company B, established in Sweden in 2013, works closely with three sister companies. There are 16 male employees with an average age of 35 years who work one shift at the Gävle-based plant. The company produces stairs and railings made from steel with a focus on firefighting stairs. Their standard portfolio of stairs allows assembly of one order within 20 hours from

the half-finished items supplied by their partners. Communication with suppliers is dominantly digital via ERP systems and emails. About 30% of orders are packed by robots, leading to a problem similar to the one faced by Company A.

3.1.3. Case C

Company C is a pulp and paper manufacturer formed in (2021). One of the production units that is in Gävle has an annual production capacity of 740,000 tons and employs approximately 900 people. The company develops and sells cardboard for food and consumer product packaging, which makes up 33% of sales. Cardboard for liquids accounts for 29% of sales and packaging cardboard 4%. Company C also develops, designs, and manufactures new fibre-based kraft and sack paper that generate 45% of sales. There are different software tools used for different processes within the company. Communication with suppliers and customers is fully digitalized and based on preliminary negotiations—production annual planning. Company C has a variety of products. The production of each product type requires different lean and digital processes. For this study, we focused on a liquid packaging product.

3.2. Methodology limitations

The study is limited to a small sample of interviews. Observations played a critical role in data collection, yet such an opportunity was restricted due to the pandemic situation. Operations plant observations were conducted only in two out of three companies—Case A and Case B. However, it was perfectly complemented by plant management interviews. There was no need for an increased number of interviews with Case A and Case B due to limited knowledge about the automated lean process of shop floor operators. Company C, in a contrast, has a bigger size of production and many employees of different levels have direct involvement and responsibility in automated lean procedures. The available resources were involved in data collection through the extended number of interviews, yet restricted access to the shop floor observation. The time constraint relevant to project deadlines restricted an opportunity to increase the number of cases, as well as access the data from countries besides Sweden, as it was planned before the pandemic.

4. Results

4.1. Company A

Table 2 is a summary of the results of Company A.

Table 2. Company A—results summary.

Underlying construct	<i>Lean practice</i>	Product-oriented technology	Service-oriented technology	Process-oriented technology
Supplier related	Automated JIT delivery	Digital waste	No problem detected	No problem detected
Internally related	Automated set-up	n/a	n/a	n/a
Customer related	Digitally involved customers	n/a	Digital waste	n/a

4.1.1. Automated JIT delivery

In cases where an order was assembled by a robot, it is possible to receive incorrect items in the order. Items are delivered in boxes and accompanied by documents listing the correct items ordered. In the case of such a robot error, the invoice is correct, but the items within the box are wrong. Consequently, the digital waste is detected in product-oriented technologies.

4.1.2. Automated setup

There is no automated setup in Company A. Each employee has their own desk to assemble the product (switchbox) from beginning to end. Printed instructions are given for each order.

4.1.3. Digitally involved customers

There is no specific software for communication with customers. Delivery is outsourced to a third company. Usually, customers respond back if the product fails. Technicians are sent out to the customer side to investigate and resolve the issue. Failure cases are stored in a common drive; however, there is no procedure to analyze failures.

4.2. Company B

Table 3 is a summary of the results of Company B.

4.2.1. Automated JIT delivery

Like Company A, Company B experiences problems with orders packed by robots. Moreover, in rare cases the suppliers do not respond for order requests, which is hard to detect in daily routines. Once the expected order is not delivered on time, the sales manager investigates the case of delay. Often, the reason is a result of a fully digital

request without a phone call reminder or confirmation. Suppliers might miss the email or attachment generated by ERP and neglect to process the order.

4.2.2. Automated setup

There is no automated setup in Company B. The manufacturer has a portfolio of products which are assembled according to the Lego principle.

4.2.3. Digitally involved customers

In very rare cases, the customer might have unique specifications where the new setup will take up to 2 hours. In some cases, the supplier might also delay the delivery due to poor digital order management and uncollected orders attached to emails from Company B. As a result, delivery to customers of company B can be delayed. Deliveries are outsourced to a post company and all the communication is fully digital. Often, delays cannot be fixed without personal interaction between management and the outsource company.

4.3. Company C

Table 4 is a summary of the results of Company C.

4.3.1. Automated JIT delivery

There is an internal system that keeps track of raw materials (sodium) in use. A signal automatically sent to a supplier monitors the consumption of the sodium. Based on a contract, the supplier is responsible to maintain the stock with X amount of sodium. If the reports collected from the machines, indicate less than X amount of sodium in the production process, the supplier arranges the delivery automatically.

Table 3. Company B—results summary.

Underlying Construct	<i>Lean practice</i>	Product-oriented technology	Service-oriented technology	Process-oriented technology
Supplier related	Automated JIT delivery	Digital waste	Digital waste	No problem detected
Internally related	Automated set-up	n/a	n/a	n/a
Customer related	Digitally involved customers	No problem detected	Digital waste	No problem detected

Table 4. Company C—results summary.

Underlying Construct	<i>Lean practice</i>	Product-oriented technology	Service-oriented technology	Process-oriented technology
Supplier related	Automated JIT delivery	No problem detected	Digital waste	No problem detected
Internally related	Automated set-up	No problem detected	No problem detected	Digital waste
Customer related	Digitally involved customers	Digital waste	No problem detected	Digital waste

Sometimes, machines might stop sending signals to the supplier due to an unknown reason. If no signal was received from the production on shift/daily basis, the supplier contacts management and confirms the status of consumed product over the phone. It also a signal to 'restart' the reporting automatically.

Currently, there are no delays occurring due to professional work of suppliers. Any delays are recorded by operators and submitted to the manager. Management analyses all the delays through the software and meets with the supplier to discuss how to solve the reason for the problem. Consequently, no digital waste was detected in process-oriented technologies in automated JIT delivery.

4.3.2. Automated setup

Setup is programmed by a production engineer with all the steps pre-assigned to all the stations. 'You teach the system, about what will happen in the shift', the production engineer says. Operators get instructions from the system. There are two (wrapping) lines—one is fully automated, the other one is half automated. The wrapping line contains many different stations. Robots pick up the material and do the wrapping. Information is constantly transformed between two systems along the whole wrapping line. One system collects information about item, another system processes that information.

The product type is very consistent; although, quality differences found in the raw material can be a challenge. Data is collected from the product every time the product is moved from one station to another. If an operator needs to replace raw material or there is a lack of raw material, operators receive a signal from the station, making a note in the system about the action, then taking the action assigned. There is a record of both actions and failures that lead to action.

Operators observe the work of the system and are responsible for confirming the placement of raw materials at different stations. They also check the equipment to prevent failures. An alarm at a station is indication that the operator needs to do something extra to prevent stoppage time. There are three shifts with eighteen operators on the shop floor. Machines are different and can vary from totally automated, to half-automated, to re-wrapping machines designed for detecting defects and damages. There are lean meetings twice a day next to the lean board, as well as in a break room.

In case of a process failure, there is a system that allows operators to record and categorize the failure. Sometimes, robots fail to pick up the item in the

wrapping line (due to a defect of raw material). The robot can be 'confused' if the raw material is missing or does not meet the required quality level. The nature of mistakes always differs, and it is hard to apply a systematic approach for their prevention. 'Our problems are dynamic', says the production engineer. 'The more you work with the alarm signals, the more you learn how to fix and prevent them'. There are several reasons for alarm signals, such as lack of information moving between systems, lack of raw material, poor quality of raw materials, lack of compatibility between two systems, defective raw materials, missing raw materials. 'The demand for quality of raw materials dramatically increased because robots are not flexible in processing poor-quality raw materials. The waste of raw material also decreased a lot. It was challenging to teach every new operator how to use the equipment manually (especially replacing items), and much of the waste resulted from the defects made by the operator at the learning stage. However, robots never caused that waste', says the production engineer.

4.3.3. Digitally involved customers

Big customers (70% of the volume) plan the orders in advance. Planned orders are saved in the internal system for the year ahead. Once the actual order is generated from the customer, it automatically appears in the system.

The orders that appearing in the system need to be confirmed by the manager before production starts. Some orders might appear with an error message in the system. Actual orders need to match a plan of total confirmed orders. Any intentional changes in color, size, quantity, or unintentional human mistakes creates errors and conflict. Each case requires investigation to detect the nature of problem—system, planning or human. It is a time-consuming process that requires extra internal meetings or external communication with customer.

The delivery of products is outsourced.

There is no data collected for the mistakes that happened during communication with customers. Yet there is software to track the communication process with customers.

5. Discussion

The aim of this study is to discover how the automation of supplier-related, internally related, and customer-related lean practices is associated with digital waste. We present our discussion based on the following definition of digital waste: "uncollected, unprocessed, and

Sometimes, machines might stop sending signals to the supplier due to an unknown reason. If no signal was received from the production on shift/daily basis, the supplier contacts management and confirms the status of consumed product over the phone. It also a signal to 'restart' the reporting automatically.

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5. Discussion

The aim of this study is to discover how the automation of supplier-related, internally related, and customer-related lean practices is associated with digital waste. We present our discussion based on the following definition of digital waste: "uncollected, unprocessed, and

misinterpreted data" (Alieva & Haartman, 2020). We present our discussion using a framework of product, process, and system levels (Enyoghasi & Badurdeen, 2021), which has been applied in the following sections to evaluate the impact of automating lean practices on the advancement of manufacturing competitiveness. We summarize these findings in Table 5, which shows the results from three cases.

5.1. Supplier-related lean practice

According to Tortorella et al. (2021), the supplier-related lean practice considers a direct involvement in the new product development process through integrated and collaborative engineering systems and digital sensors. It may also include delivery to plant on JIT aided by remote control of production, digital interfaces and IoT. In all three cases, automated JIT delivery is a supplier-related lean practice that was identified for digital waste potential.

5.1.1. Product-oriented technology

Company A and Company B experienced similar problems related to products ordered and packed by robots. Around 60% of all orders were packed by robots in Company A and 30% of all orders in Company B. About 3% of orders are wrong when packed by robots. In those cases, it is assumed that robots misinterpreted the data of the actual order and filled it with an incorrect item at the time the order was automatically received by the supplier. Consequently, it is possible to interpret the actions of robots as digital waste, as fits one of the criteria in the definition of digital waste—misinterpreted data in the production process. Company C did not face problems with automated JIT delivery using product-oriented technology.

5.1.2. Service-oriented technology

In Company A there was no problem detected with automated JIT delivery using service-oriented technology. The case of Company B poses a difficult challenge in evaluating for digital waste. On one side, problems can be interpreted as human error when the supplier misses the order leading to delays in JIT. On the other side, the agreed process excludes personal confirmation or any other form of communication between the client and supplier. Digital orders remain

the only acceptable approach. Therefore, uncollected orders by the supplier are data which can potentially be considered as digital waste. In Company C, the signal about the sodium level in the production process is very important. It can be assumed that unprocessed data with no status update about the sodium level can be potentially considered as digital waste.

5.1.3. Process-oriented technology

None of the companies experience challenges with automated JIT delivery using process-oriented technology. There was no potential for digital waste to be detected.

5.2. Internally related lean practices

Tortorella et al. (2021) discussed internally related lean practices in the context of employees' practice of time-reducing setups required to support collaborative engineering systems, improvements toward reducing setup times in plants utilizing integrated engineering systems. These systems are monitored by digital sensors integrated into collaborative engineering systems and obtained through the utilization of additive manufacturing and augmented reality. In all three cases, automated set-up is an internally related lean practice which was noted for the potential for creating digital waste.

5.2.1. Product-oriented technology

There is no automated set-up in Company A and Company B. Company C did not experience challenges in automated set-up using product-oriented technology. There was no potential for digital waste detected.

5.2.2. Service-oriented technology

There is no automated set-up in Companies A and B. Company C did not experience challenges with automated set-up using service-oriented technology. There was no potential for digital waste detected.

5.2.3. Process-oriented technology

There is no automated set-up in Company A and Company B. Company C did experience challenges with robots that, at times, failed to detect raw materials that did not meet certain quality criteria. With manual processing, shop-floor employees could adjust the

Table 5. The results summary.

Underlying construct	Lean practice	Product-oriented technology	Service-oriented technology	Process-oriented technology
Supplier related	Automated JIT delivery	Digital waste	Digital waste	No problem detected
Internally related	Automated set-up	No problem detected	No problem detected	Digital waste
Customer related	Digitally involved customers	digital Waste	Digital waste	Digital waste

whole setup process and find ways to use lesser quality raw materials. However, robots do not have that flexibility. Consequently, misinterpreted data by robots fits the definition of digital waste. However, there is a positive outcome in terms of improved quality control and higher demands to meet raw materials standards.

5.3. Customer-related lean practices

Tortorella et al. (2021) discussed customer-related lean practices in three aspects: active involvement of digital interfaces and the remote control of production; direct involvement of customers in product offerings through the utilization of process-oriented technologies, such as digital automation, remote control sensors and integrated engineering systems; share of current and future demand information with marketing departments that utilize integrated digital interfaces and engineering systems with sensors. In all three cases, digitally involved customers are a customer-related lean practice which was observed for the potential of digital waste generation.

5.3.1. Product-oriented technology

Company A does not use a specific software to collect and track customers responses in a systematic way; consequently, there is no digital waste in using product-oriented technologies. There was no problem detected for Company B in communication with customers in relation to product. In Company C, the conflict in the system between pre-planned and actual unplanned orders can be considered as a misinterpretation of data of the production process that potentially causes digital waste.

5.3.2. Service-oriented technology

In Company A there is a list of records when customers complained about the quality and requested the manufacturer to come back and fix the defect. The information is collected but never processed for further analysis to improve the quality and customer service. Consequently, we can assume that unprocessed data about failed cases from customers can potentially be considered digital waste. In Company B there are cases when digital communication failed to lead to on-time product delivery. The problem was fixed when digital communication through the automated system request was replaced by personal communication via phone calls. Consequently, the actions of the outsource delivery company can be considered as a misinterpretation of data that potentially causes digital waste. In Company C, delivery services are also outsourced, yet no problems were detected.

5.3.3. Process-oriented technology

Company A does not use a specific software to collect and track customers responses in a systematic way, so there is no digital waste in using product-oriented technologies. There were no problems detected in Company B. In Company C, there is no data collected for the mistakes that happened in communication with customers, yet there is software to track the communication. Consequently, uncollected mistakes are the data that can be considered digital waste.

5.4. Discussion summary

We find that digital waste can result from the automation of lean practices and its nature is very different depending upon the technology's orientation on product, service, or process (see Table 5). The limited number of automated lean practices in this study restricts the detection of digital waste for product-oriented technologies to only supplier and customer-related lean practices such as automated JIT delivery and digitally involved customers. A similar constraint is applied to service-oriented technologies. However, this study has no evidence of digital waste existence in internally related lean practices, such as automated set-up. The digital waste was detected with process-oriented technologies in automated set-up associated in this study as internally related automated lean practice and digitally involved customers, associated with customer-related automated lean practices. There is no evidence of digital waste in automated JIT delivery associated with a supplier-related automated lean practice for process-oriented technologies.

A detailed consideration of the source and nature of digital waste leads to the identification and significance of various forms of digital waste when the data flow of the automated lean process is either not collected, processed, or interpreted (Alieva & Haartman, 2020). This is beneficial for both the lean production approach to minimizing waste and that of the maximization of customers' value (Womack & Jones, 1990).

6. Conclusion and further work

6.1. General conclusions

The definition of digital waste as uncollected, unprocessed, and misinterpreted data (Alieva & Haartman, 2020) gives an opportunity to detect the digital waste in automated lean practices. However, in most of the actions that created a case of digital waste, poor management issues were the main and real reason for the problem. One might argue that there is no digital waste in all three cases. Instead those actions can fit the

description of the previously defined eight types of waste by Liker (2004), such as unused creativity or time wasters. However, we believe that digital waste can be a part of Liker's (2004) set of wastes if it is provoked by digital technologies integrated into lean practices. Meanwhile, there is no human interaction in errors caused by robots, which increases the extent of digital waste and encourages consider robot errors in the value stream mapping for digitalized manufacturing.

Digital waste was detected in supplier-related lean practice—automated JIT delivery—specifically in product-oriented and service-oriented technologies. Digital waste was detected in internally related lean practice—automated set-up—specifically in process-oriented technologies. Digital waste was detected in customer-related lean practice—digitally involved customers—in product-, service-, and process-oriented technologies.

6.2. Theoretical contribution

This study contributes to the theoretical discussion of both physical waste (Shah & Ward, 2007; Womack & Jones, 1990) and digital waste (Alieva & Haartman, 2020; Romero et al. 2018, 2019a) under the influence of Industry 4.0. Waste was detected in extra transport, inventory, motion, waiting, overproduction, over-processing, defects, and unused creativity (Shah & Ward, 2007; Womack & Jones, 1990). With this study, we would like to bring extra attention to digital waste appeared under the influence of digital technologies in existing manufacturing processes. The study also complements previous studies about digital waste (Alieva & Haartman, 2020; Romero et al. 2018, 2019a) by validating the definition of digital waste as well as validating the potential for its existence in lean processes. It is important to consider digital waste as a part of the original lean waste, while automated lean practices can generate waste in time, over-processing, etc. provoked by digital technologies. It also contributes to the discussion of automating lean practices (Tortorella et al. 2020, 2021) at the product, process, and system levels (Enyoghasi & Badurdeen, 2021) by validating the frameworks suggested by the authors. With this study, we validated few (but very common) automated lean practices proposed by Tortorella et al. (2020, 2021), such as automated JIT delivery, automated set-up, and digitally involved customers. The study confirmed that digital waste can potentially exist in each of mentioned automated lean practices. This study also merged the idea of product-, service-, and process-oriented technologies proposed by (Enyoghasi & Badurdeen, 2021) along with automated lean practices proposed by (Tortorella et al.

2020, 2021) to develop and validate the upgraded framework developed for further digital waste detection or/and validation in automated lean practices.

6.3. Practical contribution

This study also has several practical contributions. For example, it aims to encourage practitioners to become aware of (and detect) digital waste during the automation of lean practices, and continuously work on reducing it. This study highlights that the automation of lean practices can potentially lead to various types of digital waste as an outcome of digitizing lean processes. The fact of digital waste existence should motivate practitioners to be aimed to detect it in each digitalized process and consider the reduction or/and prevention of digital waste. Practitioners might also be motivated to consider digital waste as part of production waste and include it in value stream mapping. Reconsideration of traditional algorithms when calculating the value, as well as the waste of production processed, is essential for the accurate outcome for the practitioners. It possibly can have an influence on manufacturing managers impacting the strategy as well as supply chain collaboration tactics. Researchers and academics can also benefit from this study through exploring new research gaps related to digital waste in lean manufacturing, replicate and validate the existing study with companies of different size and locations outside of Scandinavia or/and Europe. Additionally, the topic of digital waste expands the horizon for teaching operations management with a focus on digitalization of lean manufacturing processes and extra attention on product and production data in in product-, service-, and process-oriented technologies.

6.4. Research limitations

This study discusses digital waste only in the context of lean manufacturing and is limited to Swedish manufacturing plants located in the Gävle region. There were only three cases included in the study. The main reason for such a limitation is the travel ban implemented in Europe due to the pandemic, which resulted in restrictions for companies to have visitors. The study is also limited to examining only four lean practices. The technologies discussed in the study are limited by robots for SMEs and in-house developed software systems in the third company.

6.5. Further research

Further research could investigate digital waste in other automated lean practices such as: smart suppliers'

development, automated pull, digitally controlled processes, employee involvement in digital technologies, and smart productive maintenance. We encourage replication of the study in other Scandinavian countries, elsewhere in Europe and beyond. We encourage increasing the number of cases as well as the number of interviews for each company.

There is an observation that smaller companies are less likely to automate lean processes compared to larger companies. Automation of the set-up process can be an expensive project currently unaffordable by SMEs. It is hard to detect cases of digital waste in smaller companies due to their limited budgets and small potential for digitalization as compared to bigger companies, which we also suggest for further research.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Daryl Powell  <http://orcid.org/0000-0001-7224-2306>

Data availability statement

The data that support findings of this study are available from the first author, upon reasonable request.

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