WORKING PAPER NO: 643

Lean 4.0 for customer-centric digital transformation: analysis through a work systems framework

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Year of Publication – May 2021

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Abstract

In this study we adopt work-systems framework to observe features of industry 4.0 and lean systems (ILS) – or lean 4.0 systems, and illustrate how their work-system components combine to produce a customer-centric transformation. We interpret two published cases of firms, one which ventured into industry 4.0, and other which undertook a lean approach, through this framework. We observe that while both firms ended up with a customer-centric digital transformation, industry 4.0 approach undertaken by one of the firms was largely technology-driven, while lean approach adopted by the other relied primarily on process-improvements. Our work-systems interpretation of ILS and case-discussions indicate that, synergizing lean approaches with industry 4.0 technologies – or lean 4.0 approach – seems to be a promising approach for organizations to realize customer-centric digital transformation for the future.

Keywords: Industry 4.0, Lean Production, Lean 4.0, Work System Components

Introduction

Industry 4.0 is an approach for firms to be competitive in the future through application of emerging technologies such as Cyber Physical Systems (CPS), Industrial Internet of Things (I-IoT), Big Data Analytics (BDA), Artificial Intelligence (AI), Cloud and so on (Kagermann et al. 2013). These technologies enable firms to flexibly adjust to fluctuating market demands and cater to a diversity of customer needs and expectations, while simultaneously addressing concerns attached to 'growing environmental risks and ecological scarcities' (Beier et al. 2020; Lasi et al. 2014; UNEP 2011).

Lean production systems are built on the idea of eliminating waste in the production process while adjusting to the needs and expectations of customers (Shah and Ward 2007; Womack and Jones 1997). Both industry 4.0 and lean systems are primarily aimed at similar objectives, and substantive literature point to the interdependence and synergies between industry 4.0 and lean (Sanders et al. 2016). Discussing ways in which lean production can better incorporate industry 4.0 technologies and how industry 4.0 technologies make lean production systems more efficient and transparent, they envisage a conceptual conjunction between the two approaches as lean 4.0 (Mayr et al. 2018).

In this study, we look at the socio-technical aspects of industry 4.0 and lean production systems (ILS) – or lean 4.0 systems – through work systems framework proposed by Alter (2013). While discussing various work-system components (such as processes, participants, technologies and so on) of ILS, we illustrate how such components work together to realize the customer-centric transformation expected in ILS. We also interpret two real-world cases of firms which undertook technology and process transformation through work-system framework. From the case-discussions of the two firms we observe that while both firms ended up with a customer-centric transformation, industry 4.0 approach undertaken by one of the firms was largely technology-driven, while lean approach adopted by the other relied primarily on process-improvements. We believe that a deep-dive into the inter-relationship between various work-system components of ILS can allow researchers to design novel strategies for organizations to realize customer-centric and sustainable digital transformation for being competitive in the future.

Work Systems Framework

Alter (2013) proposed a socio-technical perspective for business professionals to look at IT-reliant systems within organizations which goes beyond the frequent techno-centric perspectives which look at such systems as constituted by hardware and software used by users. According to him any system within organization whether or not an Information System (IS), can be understood as a 'work-system'. Work-system is a socio-technical system where participants (humans and/or machines) perform activities (unstructured or processual) by relying on technologies, information and other resources to produce products/services for internal or external customers (Alter 2013). Within an overarching work-systems theory, Alter proposed both static and dynamic view of a work-system. Static view of a work-system which he calls the 'work-systems framework' identifies any stable work system by its internal and external components. Components internal to such systems are 1) Processes/activities, 2) Technologies, 3) Participants, 4) Information. Components partially within such systems are 1) products/services, 2) customers. Components outside such systems are 1) Environment, 2) Strategies, 3) Infrastructure. Dynamic view of a work-system which he calls 'work-systems lifecycle model' depicts the evolution of a work-system through 'planned and unplanned' changes.

In this study, we first identify the work-system components of ILS or lean 4.0 systems. While discussing work-system components of ILS, we also illustrate how these components support each other to achieve a technology-driven, customer-centric, process transformation envisaged in ILS. Subsequently, we interpret published cases of firms which undertook technology and process transformation, through work-system framework, and highlight our preliminary observations. The two cases we discuss are: 1) Digitalization of an industrial Giant: GE takes on industrial analytics (Black and Carrick 2017), and 2) Daktronics (D): Keen on Lean Manufacturing at Daktronics, Inc. (Levenburg 2012).

Industry 4.0 and Lean systems (ILS)

Industry 4.0

Industry 4.0 is primarily a strategy for industries to be competitive in the future through application and integration of emerging technologies such as Cyber Physical Systems (CPS), Industrial Internet of Things (I-IoT), Big Data Analytics (BDA), Artificial Intelligence (AI), Cloud and so on (Kagermann et al. 2013). These technologies enable firms to adjust to fluctuating market demands and cater to a diversity of customer needs and expectations (Lasi et al. 2014; Mayr et al. 2018). Industry 4.0 approaches are also expected to address sustainability concerns attached to 'growing environmental risks and ecological scarcities' in the context of industrial production (Beier et al. 2020; UNEP 2011). Hermann et al. (2016) highlight six design principles driven by various technologies to achieve the desired objectives of industry 4.0. These principles are: interoperability, virtualization, decentralization, real-time capability, service orientation and modularity. Following are some important technologies which build industry 4.0 systems along these principles.

Interoperability ensures that interfaces of various production components are clearly understood at run-time ensuring plug-and-play capabilities. I-IoT provides identity and communication to these production components and integrates them into an industrial network. Recent advances in network technologies like software defined networking (SDN) can utilize their interoperability to dynamically reconfigure production components and their inter-connections during run-time (Kirkpatrick 2013; H. Xu et al. 2018). Building on I-IoT, Cyber Physical Systems establish a closed loop between data-acquisition from inter-connected sensors, data processing through computing software, and autonomous actuator-based control of production components (Broy 2013; Wagner et al. 2017). Integrating advanced control (e.g. SCADA – Supervisory Control and Data Acquisition, DCS – Distributed Control Systems, PLC – Programmable Logic Controller), network (e.g. SDN, 5G, M2M – Machine to Machine communication) and computing infrastructure (Cloud, Edge and Fog Computing), CPS ensures digital representation or *virtualization* of various components in the production process (H. Xu et al. 2018). Further, CPS ensures human-machine interfaces based on virtual/augmented reality, extending physical and cognitive capabilities of human operators within the production process (Zolotová et al. 2020). Technologies like AI and BDA help production components to gather and analyze data, take decisions, and autonomously organize themselves in real-time, thereby facilitating *decentralization* and *real-time capability* in industry 4.0 production systems. These capabilities also enable production components to synchronize themselves with entire value stream – inputs from suppliers to delivery of products/services to end-customers (Kagermann et al. 2013; Sanders et al. 2016). Virtualization of production components enabled by CPS allows production systems to be conceived as a combination of software services which can be developed by independent contributors and made available through Internet of Service (Mrugalska and Wyrwicka 2017). Customized and innovative designs can be realized through such a *service-oriented* architecture within production systems of industry 4.0 (Verma et al. 2017). Lastly, production components and their virtual counterparts are, are integrated as modules into larger production systems by taking into account their physical dynamics and computational constraints (Lee 2008). This *modular* approach which allows dynamical adjustment, expansion or re-configuration of component modules and their inter-connections contributes to flexibility of the production system (Vogel-Heuser and Hess 2016).

From a macro-perspective, industry 4.0 is expected to achieve horizontal integration connecting value creation modules cutting across companies in a value creation network, vertical integration connecting entities at different hierarchical levels from machine-level until enterprise planning level, and end-to-end integration connecting all phases of a product's life-cycle (Stock and Seliger 2016). It is also expected to shift the nature of work performed by humans towards decision-making and flexible problem solving, by supporting them with context-specific information in real-time (Gorecky et al. 2014). Through all this, industry 4.0 is expected to realize 'smart' factories of the future (GTAI 2014) - enabled by smart products, machines, planners and operators. 'Smart Products know their production process and negotiate it with Smart Machines', 'Smart Planner optimizes processes in nearly real time', and humans with support from technologies become smart operators supervising and controlling ongoing activities in the production process (Kolberg and Zühlke 2015).

Lean Production

Lean production systems are built on the idea of eliminating waste in the production process while being customer-centric. According to Womack and Jones (1997), lean thinking proceeds through five key steps. First is to identify what constitutes *'value'* for a customer – their customization needs and expectations. Second is to identify a *'value stream'* which specifies the value to customer added by each activity taken up during the process of realizing a product – from design to delivery. After eliminating wasteful activities in within the value stream, third step is to make sure that all the value-creating activities *'flow'* without any bottlenecks and with least inventory usage. Achieving these steps allow producers to produce for the exact needs and expectations of customers and transform hitherto 'batch production' into 'pull production' where customers can now *'pull'* products they value from the producers. Lastly, lean thinking calls for *'perfecting'* activities within value stream by minimizing their variability and continually trying to reduce different kinds of wastes during the production process – such as over production, over processing, excess inventory, unnecessary motion/transportation of materials or humans, unwanted material waiting times, and defects (Shah and Ward 2007). These steps of lean-thinking are equally applicable to the realization of services (Piercy and Rich 2009).

The aforementioned lean thinking principles manifest as various activities within lean production systems. These activities are elucidated by Sanders et al. (2016) under four main categories – supplier, customer, process, control and human – based on a more finer categorization proposed by Shah and Ward (2007). Just-in-time delivery of inputs from suppliers, passing customer feedback on final products back to suppliers, and knowledge exchange with suppliers to develop them along with producers – constitute activities within the supplier category. As customers are the prime drivers of business for producers in the context of lean, capturing the needs and expectations of customers and involving them in the production process constitute activities within the customer category. Maintaining flow of activities constituting the value stream without large halts, and facilitating such flow through Kanban systems or just-in-time production - where initiation of need from down-stream consumers drives the flow of material from up-stream suppliers – constitute activities within the process category. Prevention of failures through periodic maintenance activities, ensuring low-rectification times for resolving failures, stopping defects from percolating through the process, and engaging employees in continued improvement of the processes, constitute activities within the control and human category. Activities that fall within the human category also make lean production systems stand ahead of mass production systems. Lean production systems are concerned with empowerment and meaningful integration of employees by giving them adequate flexibility and autonomy within the production process. Lean organizations are known to retain productive workers for longer by providing them with diverse and flexible career mobility paths in comparison to organizations based on mass production (Mrugalska and Wyrwicka 2017; Womack et al. 2007).

Lean 4.0 - conjunction of industry 4.0 and lean

Studies point to the interdependence between industry 4.0 and lean by discussing ways in which lean production can better incorporate industry 4.0 technologies and how industry 4.0 technologies can make lean production systems more efficient and transparent (Bittencourt et al. 2019; Kolberg and Zühlke 2015; Mrugalska and Wyrwicka 2017; Sanders et al. 2016). Mayr et al. (2018) summarize how lean production systems can be more receptive to industry 4.0 technologies under three points. First, 'standardized, transparent, and reproducible processes' perfected over time in lean production systems are significant for incorporating industry 4.0 technologies, because inefficient processes will only magnify inefficiencies. Second, guided by experienced decision-makers who mastered lean processes, organizations can organically integrate industry 4.0 technologies into existing processes to realize the outcomes common to both lean and industry 4.0 – i.e., customer-driven production and reduction of waste for addressing sustainability concerns. Third, lean production process reduces the product and process complexity by clearly identifying value for customer, and minimizing non-value adding activities within the value stream; this also leads to 'efficient and economic use' of industry 4.0 tools. With regard to dependence of lean on industry 4.0, Sanders et al. (2016) identify the key technologies of industry 4.0 which can improve activities associated with supplier, customer, process, control and human categories, within lean production systems. Kolberg and Zühlke (2015) provide a framework connecting industry 4.0 and lean by comparing how smart operators, machines, planners and products can help realize just-in-time and timely addressing of failures in lean production systems. Mayr et al. (2018) discuss the conjunction of industry 4.0 and lean – or lean 4.0, and arrive at various possibilities for technology enhanced lean methods.

Key work systems components in ILS

In the aforementioned sections we looked at 1) objectives, technological infrastructure, and expected outcomes of industry 4.0 production systems, 2) principles of lean thinking, and activities that help firms to realize the expected outcomes of lean production, and 3) interdependence between industry 4.0 and lean that firms can exploit to reap the best of both worlds. By doing this, we outlined some of the essential technological infrastructure, organizational environment and strategies which underpin industry 4.0 and lean systems (ILS). According to Alter (2013), environment, infrastructure and strategies are components which lie outside the work-system but are critical to holding the work-system components together. In the context of ILS, infrastructure includes the interoperable control, computing and networking infrastructure which forms the base for designing flexible production systems. Environment encompasses a lean organization's receptiveness for incorporating industry 4.0 technologies. Lastly, customer-driven and sustainability-oriented objectives form the key strategies driving work-systems of industry 4.0 and lean. In this section, we look at the other work-system components in ILS which operate (a) partly within and partly outside the work system - customers and products/services, and (b) completely within the work system - processes and activities, participants, information and technologies. While discussing these work-system components we also illustrate how they relate to each other in contributing to the customer-centric transformation expected in ILS.

Customers and products/services

Both industry 4.0 and lean approaches give primacy to customers. Customers are the key drivers of business, and work-systems of ILS are expected to be flexible in responding to a diversity of customer needs and expectations. They should be able to identify what constitutes 'value' for customers, specify value stream and its constituent activities, and perfect the flow of these activities with minimal waste so that customers can pull value-added products/services out of the production process (Sanders et al. 2016; Womack and Jones 1997). Interoperable technological infrastructure adds to the flexibility of production process. Cyber physical systems built over such infrastructure can facilitate dynamic adjustment of product specifications extending the product freeze period for customers who can adjust their product requirements even at later stages until product parameters become unchangeable (Lasi et al. 2014; Sanders et al. 2016). Vertical integration is facilitated within ILS where process aware information systems (PAIS) – built over flexible, inter-connected, and virtually accessible autonomous production modules – connect activities from shop-floor all the way up to enterprise planning levels (L. D. Xu et al. 2018). These PAIS allow development of service-oriented applications that can a) keep customers aware of the current status of production so that they could track their order in real-time (Cannata et al. 2008), and b) incorporate customer feedback, product usage history, customer needs and expectations, back into the production process (Mrugalska and Wyrwicka 2017). This not only allows 'mass customization' of products catering to a variety of customer needs and expectations (Lasi et al. 2014), but also, products pulled by customers can be augmented with additional services like suggesting maintenance schedules, predicting faults and other value-added services (Sanders et al. 2016).

Components which make up the product can themselves be embedded with information about which activities within value stream they would progress along, which machines they would interact with, and what eventual customized product they would go into (Kolberg and Zühlke 2015; Wagner et al. 2017). Machines are expected to communicate with product components and dynamically adjust work-loads based on capacity constraints they face during run-time so as to deliver products with optimal quality (Brettel et al. 2017). Tagged products and their parts enable operators to track their flow through the production process and detect failures early-on and avoid propagation of defective products/parts through the value stream (Mayr et al. 2018; Sanders et al. 2016).

Processes and activities

Sanders et al. (2016) discuss how industry 4.0 technologies can enable pull production, continuous flow, and setup time reduction expected in lean production systems. Pull production requires that demand for production must arise from customers and every up-stream producer must produce as per the demand of the down-stream consumer within the value stream. This just-in-time production is typically carried out through Kanban method in lean production systems where Kanban cards are exchanged between up-stream producers and down-stream consumers to initiate material flow from former to the latter in small batches. It ensures that flow of materials, semi-finished and finished goods, to flow continuously and avoid large halts and excess inventories accumulating between producers and consumers (Sanders et al. 2016; Wagner et al. 2017). Kanban system ensures that participants within a process-step self-organize their production activities based on their up-stream producers and down-stream consumers (Mayr et al. 2018). Technologies like RFID can help in transforming Kanban into e-Kanban, where empty bins are automatically recognized and trigger is sent to upstream producers (Kolberg and Zühlke 2015). Technologies such as AI and BDA can exploit processual data and enable self-organizing capabilities to production components so that activities within the value-stream become transparent and value can flow through the process more effectively. For instance, analyzing information exchanged between networked production components and transferring material away from capacity-constrained machines towards other less-constrained machines can improve process flow (Brettel et al. 2017; Sanders et al. 2016). As firms realize autonomous and self-organizing production components, firms can adapt to dynamic changes in product specifications or amount of products demanded, thereby reducing setup times in operations (Sanders et al. 2016).

Participants, information and technologies

Technologies like CPS and I-IoT create flexible, modular and decentralized production systems within ILS enabling them to be responsive to a diversity of customer needs and expectations (H. Xu et al. 2018). As customer requirements need to be synchronized with up-stream process-steps or activities within the value-stream, information flow needs to happen in almost real-time (Sanders et al. 2016). Communication and networking technologies ensure real-time information flow not just between machines, but also between machines and humans and between humans. Considered as the most flexible entities in ILS, humans are expected to play the role of decision-makers and flexible problem solvers (Gorecky et al. 2014; Mrugalska and Wyrwicka 2017). As technologies such as CPS bridge the gap between physical and virtual worlds, decision-making and social-interaction based skills, which are difficult to evolve in the cyber world now fall into the hands of humans (Waschull et al. 2020). Data acquisition, information processing and computing technologies act together to supply individualized information to workers about the overall context and immediate surroundings in which they work (Fantini et al. 2020; Krugh and Mears 2018). Machine learning models trained on processual-data of the past can provide predictive insights that can support human operators to detect critical events in advance, timely alert others on-site, and quickly respond to failures during the production process (Fantini et al. 2020; Kolberg and Zühlke 2015). Human-machine interaction technologies such as dialogue systems, multimedia displays, adaptive interfaces, and virtual/augmented reality devices, further extend the physical and cognitive capabilities of humans during the production process transforming them into smart operators (Zolotová et al. 2020).

Following Figure-1 summarizes the work-system components in ILS. Organizational environment, strategies and infrastructure lie outside the work-system but hold the other components together. Customers and products/services are components partly within and partly outside the work-system. Processes and activities, participants, information and technologies operate within the work-system.

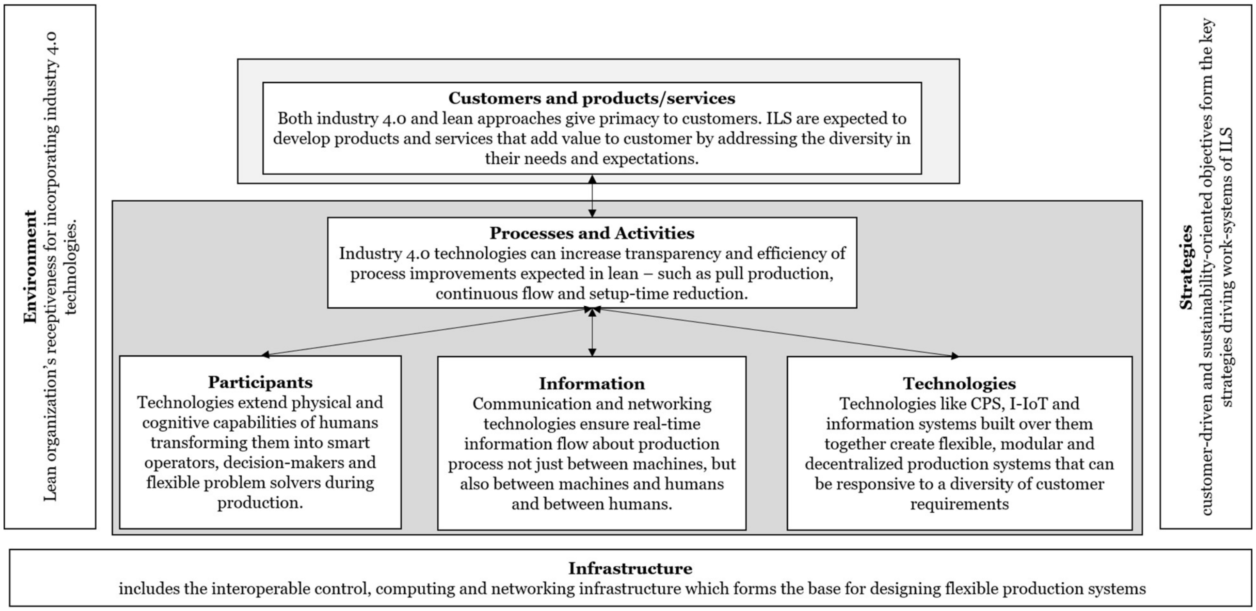

Figure 1: Work-System Components in ILS

Interpreting real-world cases through work systems framework

Case of General Electric (GE) adopting industry 4.0

In the case-study by Black and Carrick (2017), the authors describe in detail the rationale for GE's adoption of industry 4.0 technologies, and how they implemented them. Here we present a brief overview of this case and summarize it through work-systems framework (Alter 2013).

GE was traditionally an industrial hardware company which profited from the sale of its products to customers and through customer service agreements (CSAs) which generated steady stream of revenues by servicing products during their life-time. For a long-time GE enjoyed lead in the sciences underpinning their products. But as others caught up, GE now faced a challenge to differentiate their products from its competitors to gain competitive advantage. For this GE looked at two areas 1) predictive maintenance, and 2) process optimization where they can contribute to customer benefits through their products. Predictive maintenance of their products was expected to prevent unplanned maintenance losses for customers. As GE's customers dealt with high-fixed cost business operations, any process optimization gave them staggering benefits. Since several of GE's products were part of customer value-streams, GE had thought of self-optimizing their own product functionality for improving efficiency in customer's business processes. GE developed a cloud-based software platform called 'Predix', which was capable of gathering data from GE's products via sensors, and analyze them to generate actionable insights for improving customer's business processes. GE opined that developing software platform which best suits their own products, will add value to customers, more than any generic software platform agnostic to product owners. However, as customer value-streams had products or components that were also from other manufacturers, GE latter collaborated with Accenture to develop another software platform called 'Taleris' which customers could employ irrespective of who manufactured components in their value-stream. Through this additional service, GE has been successful in utilizing in-house capabilities to drive further value to customers.

Looking though work-systems framework we observe that GE's digital transformation is largely driven by augmenting their existing products with services that benefit customers, in an attempt to gain competitive advantage. Software platforms that were developed in this transformation combined information gathered from GE's own products functioning within customer value-streams. To work-system that was already developing industrial products, GE added technologies that would acquire, process and analyze information gathered from their products in order to augment them with intelligent operations services for the benefit of its customers.

Case of Daktronics adopting lean production

In the case-study by Levenburg (2012), the author describes the fruitful journey of Daktronics in transforming its production process following lean principles. Here we present a brief overview of this case and summarize it through work-systems framework (Alter 2013).

The transformation journey of Daktronics to lean was mainly for scalability reasons. Before it's formal transition to lean began, Daktronics scaled its operations by replicating its production facilities, equipment and processes. Their existing batch production strategies which relied on large product orders with lower margins seemed less profitable for the company. Daktronics transformed its production process into lean by taking a modular approach for manufacturing. Recruiting lean consultants, it empowered its workforce to address inefficiencies and standardize various process-steps or activities that made up its value-stream. It started to build customized products for customers, by integrating significant percentage of standard component modules. As most of their orders were based on fixed-price contracts, lean provided a way to recover cost overruns, by reducing lead-times between customer order placement and final product delivery. Further an ERP system was deployed to facilitate communication with customer in terms of order placement and customer service, and internally between sales, design, production and delivery teams.

Looking through a work-systems framework we observe that process-improvement for scaling operations has been key for Daktronics to undertake its lean journey. Eliminating waste and standardizing process-steps within their value-stream, allowed Daktronics to avoid cost over-runs and achieve cost-savings given their fixed-price contracts. Modularizing production components allowed Daktronics to provide customized products demanded by customers. ERP system allowed transparency in information exchange between participants – both internal teams and external customers.

From the discussion of these cases, we see that in case of GE, adopting industry 4.0 approach has been primarily a technological undertaking beyond their existing production process. Within their customer-centric digital transformation, technological platforms helped GE to provide value-added services to customers along with their hardware products. On the other hand, in case of Daktronics, the approach has been primarily a process improvement undertaking more than a technological one. Process improvements through lean helped them minimize wasteful activities within their production process to save costs, and producing modularized components as part of such improvements also took them closer to the customization requirements of their customers. Although both approaches are customer-centric and address resource sustainability concerns, from a work-systems view, industry 4.0 approaches in our cases, turned out being more technology-driven, while lean approaches, primarily process-oriented. Our analysis from the work system perspective, implies that among other things, a genuine lean4.0 system has to incorporate both technology changes and process changes simultaneously.

Conclusion

The synergies in Industry4.0 and lean productions systems are being discussing in the emergent literature on lean4.0. We feel that an overarching framework to analyze this development is provided by the Work-Systems Framework. The advantage of this framework is that it goes into the building-blocs of work in an organization and thus enables to classify and chart-out the varying trajectories that lean4.0 transformations can take. Work-systems framework allowed us to describe various work-system components constituting industry 4.0 and lean systems and illustrate how such components work together to create flexible production systems which can address variety in the needs and expectations of customers. There is a fair amount of theoretical literature in this field and we chose to understand its applicatory potential by picking up two specific cases that undertook such transformations. The framework we followed, that of work-systems allowed us to interpret technology and process transformations undertaken by two firms GE and

Daktronics as narrated in the case-studies. From the interpretation of these two cases through work-systems framework, we observe that industry 4.0 approaches are more technology-driven, while lean approaches are primarily process-oriented. Our work-systems interpretation of ILS and case-discussions indicate that, synergizing lean approaches with industry 4.0 technologies – or lean 4.0 approach – seems to be a promising approach for organizations to realize customer-centric and sustainable digital transformation for the future. But ensuring that would call for a more nuanced understanding of the work-systems of organizations that the Work-systems framework elucidates.

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