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Paradoxes in the Digital Transformation of Production Systems

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Abstract. Digital transformation of production systems is a challenging task that demands radical responses from existing organizations. During the digital transformation of productions systems tensions occur that need to be managed and the purpose of this paper is to identify paradoxes in the digital transformation of production systems. Paradox theory has been applied as an analytical framework when identifying digital transformation paradoxes and tensions. A case study has been conducted and two manufacturing companies' digitalization projects have been studied and analyzed in combination with data from workshops around digital transformation. The results were mapped into four types of paradoxes: organizing, performing, belonging, and learning. We conclude that the identified tensions are intertwined, and a major tension is the degree of standardization of technologies (standardization vs customization) and a more agile way of working (learning by doing vs learning before) doing is a trend within the digital transformation of production system. Our findings are relevant to operations managers and others interested in tensions during the digital transformation of production systems.

Keywords. Smart production, digitalization, case study, manufacturing industry, Industry 4.0

1. Introduction

Digital transformation of production systems and the creation of a smart production system is a transformation towards a more competitive and sustainable production. This ideal future state can be achieved with the integration and usage of digital technologies that enable the creation of a smart production system [1]. Digital transformation is a change process and this process has been studied from different perspectives such as enabling technologies, barriers, and goals [2-4], readiness and maturity [5, 6], strategy [7, 8], and future research areas [9, 10], etc. Dieste et al. [11] describe that while implementing Industry 4.0, organizational environments become more global, dynamic, and competitive thereby intensifying contradictory demands. Also, Sjödin et al. [1]

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discuss that companies face immense challenges in implementing smart factories, given the large-scale, systemic transformation the transition requires.

In turbulent contexts, manufacturing companies face contradictory challenges which give rise to management tensions [12]. Digital transformation is one such context where the disruptive potential of digital technologies demands radical responses from existing organizations [12]. Digital transformation cause paradoxes that need to be managed and the importance of ambidextrous organizations (exploitation vs exploration) is often discussed in the literature [4, 13, 14].

The paradox lens offers valuable insights into effectively managing contradictions within organizations and for management science, providing a deeper understandings of constructs, relationships, and dynamics surrounding organizational tensions [15]. By adopting the paradox theory as a framework, we seek to enhance our understanding of the tensions inherent in the digital transformation of production systems. Lewis [16] defines a "paradox" as a conflict between opposing forces that are interrelated, persist over time and likely coexist and should thus be managed in conjunction. Further, Schad [15] defines a "paradox" as the persistent contradiction between interdependent elements". We follow the view of Schad and see a paradox as a contradictive force that needs to be managed and dealt with. Paradoxes and tensions are often discussed in terms of old vs new, stability vs change, and present vs future [17]. Finding the right level or balancing these contradictory tensions is essential to optimize performance and vital for sustainable production system development and in the creation of a smart production system. Paradoxes are characterized by the coexistence of seemingly logical yet contradictory elements that appear absurd and irrational when observed together. By recognizing and comprehending these paradoxes, we can navigate the complexities of production systems development with a more nuanced perspective.

Therefore, the purpose is to identify paradoxes in the digital transformation of production systems. As organizations increasingly face contradictory goals, multiple stakeholder expectations, and pluralistic missions that surface and intensify competing demands [18], the identified paradoxes need to be managed and manufacturing companies have the potential to develop possible countermeasures.

The remainder of the paper is outlined as follows. First, the theoretical framework is outlined, followed by a description of the research methodology. Thereafter, the empirical findings are presented, starting with describing the identified paradoxes, followed by a summary of paradoxes and tensions. Finally, the identified paradoxes, problems, and tensions are discussed as well as the research limitations and future research directions.

2. Theoretical framework

This section starts by introducing digital transformation and digitalization of production systems, followed by production system development as a process and way of working. Finally, an overview of paradox theory as an analytical framework is provided.

2.1. Digital transformation and digitalization of production system

The terms digital transformation and digitalization are often used interchangeably in the literature and the terms are not well defined [19]. Vial [9] reviewed 282 articles and found 28 sources that provided 23 unique definitions of digital transformation. The many

definitions and descriptions of digital transformation show that various aspects are transformed, such as people, culture, mindset, talent development and leadership, business models, organizational structure, and so on [9, 20, 21]. Digitalization on the other hand is often described as the work at operational level [19]. Savastano, et al. [22] describe digitalization as the use of digital data and technology to automate and optimize processes. From a theoretical perspective, the main enabler of digital transformation and digitalization is the use and integration of digital technologies with the end goal of creating value that creates competitive advantages [21].

2.2. Production system development as a process and way of working

A production system can be described as an interacting combination at any level of complexity, of people, material, tools, machines, software facilities, and procedures designed to work together for some common purpose. This description highlights the entangled elements of a production system, all of which need to adapt and transform during the digital transformation. Notably, the emphasis is not only on the physical assets but also on the many interactions and other soft aspects.

Many manufacturing companies use stage-gate based models for following-up progress of projects [23]. Cocchi, et al. [24] highlight that stage-gate hybridization is becoming progressively popular among manufacturing organizations that integrate iterative methodologies such as agile into the linear stage-gate process to create hybrid development models and face higher uncertainty. Also, Brosseau, et al. [25] discuss that traditional organizations are built around a static, siloed, structural hierarchy, whereas agile organizations are characterized as a network of teams operating in rapid learning and decision-making cycles. Agile or agile scrum development processes have their roots within software development [26]. According to Peeters, et al. [26], project teams working in an agile way should be self-managing, self-reflective, have a quick product turnaround, make efficient use of their resources, work in close collaboration with their stakeholders and interact primarily through face-to-face communication.

There are many differences between stage-gate and agile scrum models regarding way of working. Sjödin, et al. [1] found that manufacturing companies face difficulties in changing traditional routines and work processes to affect the digital transformation. Factories frequently lack a systematic approach to adopting modern project models that enable more agile and flexible results and faster time-to-market. This shows the difficulties of changing from a stage-gate based way of working to an agile model and way of working. Regardless of development model used all development takes time, involves people and experiments, and requires learning. In this development process several learning modes occur that range from learning before doing to learning by doing [27, 28].

2.3. Paradoxes in digital transformation of production system

A paradox can be defined as a contradictory yet interrelated elements that exist simultaneously and persist over time [17]. Smith and Lewis [17] describe that its core paradox theory presumes that tensions are integral to complex systems and that sustainability depends on attending to contradictory yet interwoven demands simultaneously. Within paradox theory, tensions are seen as the underlying sources of a paradox and four types of interrelated paradoxes: performing, learning, organizing, and belonging are frequently used in studies [16, 29].

Organizing paradoxes refer to tensions that arise through competing designs and processes, such as rigid alignment vs flexibility or empowering employee's vs leading [11]. Performing paradoxes deal with internal and external demands between goals and performance [15]. For example, development of new capabilities vs performing in current business is something that causes tensions when it comes to digital transformation [11]. Learning paradoxes stem from innovation and change processes [11]. These paradoxes include tensions between internalized knowledge and the uncertainty of the future, e.g., adaptive culture vs rigid culture [30]. Belonging paradoxes are generally conflicting demands that arise between the individual and the collective and between competing values, roles, and memberships [11].

Paradox theory has been applied when studying innovation [13], sustainability [31], digital transformation [11, 12, 30, 32], circular economy [33], lean implementation [29, 34], change [35], and decision making [36]. Digital transformation of production systems is a challenging task which raises many paradoxical demands [12]. In Table 1 digital transformation paradoxes discussed in the literature are summarized.

Table 1 Digital transformation paradoxes discussed in the literature.

Paradox of	Paradox
Belonging	Department objective vs Business unit objective [11] Autonomy vs Agreement in decision making, Collaboration vs Risk of security threat, Centralization vs Decentralization, Common objective vs Individual goals, Standardization vs Customization [30] Inner vs Outer renewal contexts [32]
Organizing	Facilitate proactive behavior vs Maintaining efficiency, Empowering employee's vs Leading [11] Global strategy vs regional entrepreneurialism [12] Competition vs Collaboration, Flexibility vs Efficiency, Centralization vs Decentralization, Adaptability vs Competency, Operations streamlining vs Operations reconfiguration, Resource conservation vs Abundancy [30] Deliberate vs emergent renewal practices [32]
Performing	Operational performance vs Sustainability objectives [11] Build new capabilities vs Perform in current business [12] Short term economic gain vs Long term sustainability, Environmental Risk Reduction vs Vulnerability Reduction [30]
Learning	Adaptive culture vs rigid culture, Radical technological change vs Incremental technological changes, Flexible organizational mindset vs Routine mindset [11] Clear communication vs Continuous learning [12] New digital competencies vs Existing competencies, Adaptive culture vs Rigid culture, Flexible organizational mindset vs Routine mindset, Perceived future economic gain vs Short term investment, Radical technological change vs Incremental technological changes [30] Established vs Renewed technology usage [32]

3. Research method

This section starts by describing the research design and study context, followed by data collection and analysis.

3.1. Research design and company selection

As the purpose of the paper is to identify tensions in the digital transformation of production system, a case study was conducted. This method was chosen because it can help obtain a detailed understanding of the phenomenon being studied [37, 38].

Furthermore, it can provide the opportunity to use different techniques for data collection and sourcing, thus supporting the ability to gather a rich set of data from observation, interviews, documents, etc. [39]. This study is a part of a larger research project conducted in collaboration with four manufacturing companies located in Sweden. The research project focuses on digital transformation, but in this paper two case companies (labelled company A and B) digitalization projects are analyzed and discussed. Thus, the data collected covers both digital transformation as a bigger concept and digitalization as the work at the operational level [21, 22]. Both manufacturing companies are spread globally through international manufacturing networks. Further, they have both local (at the production site) and global (centralized and not belonging to production sites) support functions. Both companies applied the concept of core plants: dedicated production sites serving as centers of excellence, have a central role in knowledge creation and must ensure that the latest knowledge is diffused throughout the organization's production network [40-42].

Company A is a manufacturing company within the automotive industry and has 30,000 employees located in 33 countries. The participants in this study worked at both global and local support functions in different areas connected to digital transformation. Company A has an organizational structure that is linked to global and local initiatives, and roadmaps for technology development have been created per technology area. Recent digitalization initiatives in the company involve the introduction of IIoT platforms, Big Data and Edge computing as well as the introduction of co-bots and autonomous transports.

Company B is a manufacturing company within the manufacturing industry and has over 43,000 employees located in more than 40 countries. The participants in this study worked at both global and local support functions, with a focus on digital transformation. Company B is working towards its vision of a future factory and focuses on the standardization of technologies in general and information technology (IT) infrastructure in particular. Recent initiatives include the introduction of shop floor LAN. The standardization of technologies is performed at the global level.

This study used various data collection techniques described in section 3.3 to understand how the participating companies approach digital transformation and work with digitalization of production systems. In Table 2, the job titles of the project participants are described.

Table 2 Job title of project participants. *Shows interviewed personnel in the two digitalization projects

Company	Job title
A	Global R&D, manufacturing engineering, program office manager, technology transformation manager, manager manufacturing engineering development, project manager*, production engineer x2*, IT & Digitalization*
B	Manager reliability and future factory, manager process and manufacturing development*, technical lead manufacturing it, director regional it and central services*

3.2. Case descriptions

The studied digitalization project at company A was from the beginning not a planned project. Due to external factors this project was initiated and performed under extreme time pressure. A new production line had to be invested in and designed, and there was no clear vision or strategy available for creating a smart production system at the company. The project team had to define their own digitalization vison and strategy of

how the production line should operate and be designed. As a starting point the project team wrote down their vison and defined how the production line would look like and operate. Some key elements in the vision were highly flexible (product, volume), highly automated, and connected with the help of digital technologies. The project team applied an outside of the box thinking when starting the project with an attitude nothing is impossible. In the project team every thought and idea counted even though no available technical solutions existed or planned activities for achieving the vision.

The studied digitalization project at company B was a planned project. The company worked towards a vision of a future factory with a focus on standardization of technologies. Particularly there was a need for and focus on a standardized information technology (IT) architecture. The studied digital transformation project included the introduction of a shop floor local area network (LAN). The standardization of technologies was performed at the global level and the creation of a shop floor LAN network was seen as a necessary step towards the vision of a future factory. The main goal of the shop floor LAN project was to enable a full data value chain, i.e., production planning and control.

3.3. Data collection and analysis

In this study paradox theory was used as an analytical lens for identifying paradoxes and tensions when analyzing the data (see Table 1). Data was collected through interviews, company visits and presentations, and from workshops with the research project participants (see Table 3). As a starting point, both case companies picked one completed digitalization project of production system. These projects or use cases were studied through 1) use cases presented at project meetings by the company, 2) company visit and demonstration of achievement in the project, 3) interviews focusing on four areas (role in project, strategy and roadmap, way of working, insights and lessons learned) with involved personnel in the digitalization project. The collected data was then cross analyzed through the paradox lens.

Table 3 Summary of data collected.

	No. of	Topic and length
Workshop focusing on digital transformation and digitalization	4	1: Company presentation around how they approach digital transformation and digitalization challenges 180 min 2: Discussion around the meaning of digital transformation and digitalization as concepts 180 min 3: Digital transformation and digitalization challenges workshop 180 min 4: Difficulties with pilot to scale-up during digitalization 180min
Digitalization project	2	Case A (Company visit and presentation of studied digitalization project/7hour) Case B (Company visit and presentation of studied digitalization project/7hour)
Interview	6	Case A Case B (Insights and lessons learned from digitalization project/30 to 45min)

4. Paradoxes in the digital transformation of production systems

Based on the empirical findings the following main paradoxes have been identified. The identified paradoxes are divided into belonging, organizing, performing, and learning.

4.1. Paradox of belonging

Both case companies had an organizational structure that divided resources into local (production site) and global level (no belonging to specific production site). At the local level all hands-on work was performed at the production site when integrating digital technologies and at global level new technical digital solutions were developed and standardized for increased transferability between production sites. The main idea with having resources at a global level was to give support to production sites when needed, develop standardized solutions (bookshelf solutions), and to have a holistic view of respectively production sites need. In a way the role of the resources working at global level was to pre-develop digital technical solutions that were standardized and easy to implement.

The findings from case A showed that the global digitalization resources were not involved in the project from the beginning. All technology development was performed at the production site and the resources involved had limited knowledge when it comes to designing an IoT architecture, machine connectivity (M2M) and system integration. System integration knowledge was lacking at the production site while knowledge around advanced robotics and new manufacturing technologies existed. When global digitalization resources were involved in the project the digitalization project accelerated in performance, but there was some amount work that had to be done in order to clean up some previous work done.

The findings from case B showed that the main tension was how to manage innovation capability at each production site. At the production sites the resources were innovative and developed their own technical solutions. Two main reasons for the productions sites developing their own technical solutions were 1) the legacy system at the production sites, and 2) development of new technical solutions at global level took too long time. Innovation capability was considered as something wanted from a company perspective, but in this context, it had consequences for degree of standardization and transferability of technical solutions.

This causes the problem: where should technological development be performed?

4.2. Paradox and tension of organizing

The findings from case A showed that a traditional stage-gate process was used in the project, but the extreme time pressure forced the project team to apply a more agile or scrum way of working in order to complete the project in time. For example, the project team bought robots and automated guided vehicles (AGV). A new technical solution was developed by combining these technologies for increased automation and flexibility, and this development was performed during the project. In short, the main part of all technology development and solutions in the project was performed in the project. Development of new technologies during integration projects break against the idea of predevelopment of technologies. The main idea with predevelopment is to minimize risk or uncertainty as well develop a robust solution. However, the global digitalization resource involved as IT architect and for connectivity described this project as highly agile and with no available bookshelf solutions for connectivity. The IT architecture had to be adapted and the best way to do adapt the architecture was in an ongoing project.

The findings from case B showed that the first version of the LAN network was developed at home by a highly engaged engineer. By applying an explorative approach with high degree of learning by doing the engineer started to develop an architecture that

connected devices at home, i.e., creation of a smart home. Based on the learnings from this approach key elements and learning outcomes were transferred to the creation of an LAN network at the case company.

This causes the problem: how should digitalization of productions system be performed?

4.3. Paradox and tension of performing

As described in the paradox of belonging and organizing both case companies wanted to develop standardized digital solutions that could be transferred and applied at different production sites in their manufacturing network.

The findings from case A showed that new technical solutions were developed during the project and connectivity solutions developed in the project could and were transferred to other production sites at the company. The developed connectivity solution was simple and cheap and could therefore be transferred to smaller production sites with less financial resources. The case company saw many benefits with this solution and specifically in financial terms and as a spin-off from the initial digitalization project.

The findings from case B showed that the first version of the LAN network was developed at home by a highly engaged engineer and at production sites the resources were innovative and developed their own technical solutions. The explanation given to this innovative development at individual level and at production sites was that global development and degree of standardization took too long time.

This causes the problem: to what degree should digital technologies be standardized and transferable between production sites?

4.4. Paradox and tension of learning

Learning and knowledge development can take many forms and in the literature learning before doing and learning by doing is discussed when it comes to technological innovation. As described in the paradox of belonging, organizing, and performing, the main paradoxes in the digitalization of production system cover the degree of standardization and way of working.

The findings from case A showed that many development activities were a combination of learning before doing and learning by doing. Simulation of production concepts was used for creating understanding of concepts, but many development activities were performed by learning by doing. The highly agile way of working forced many development activities to be hands-on with a high degree of learning by doing.

The findings from case B showed that the first version of a LAN was developed by an engineer who explored different technologies at home when creating a smart home. The engaged engineer designed a LAN at home and learned by doing and transferred the gained knowledge into the digitalization project.

This causes the problem: how should technological knowledge be developed?

4.5. Summary of paradoxes and tensions

In Table 4 a summary of identified problems, tensions, and paradoxes is described. Paradoxes during digitalization of production systems arise from all four categories.

Table 4 Summary of identified problems, tensions, and paradoxes. (Table adapted from Lusher and Lewis [43])

Paradoxes of	Problem or dilemma	Tension	Paradox
Belonging	Where should technological development be performed?	Should technology development be performed locally or globally?	Local vs global development
Organizing	How should digitalization of productions system be performed?	Should the development process be controlled or flexible?	Stage-gate vs agile process
Performing	To what degree should digital technologies be standardized and transferable between production sites?	Should technologies be standardized or customized?	Standardization vs customization
Learning	How should technological knowledge be developed?	Should learning take place before implementing or learning by implementing?	Learning before doing vs learning by doing

5. Discussion

The purpose of the paper was to identify paradoxes in the digital transformation of production systems. The research presented has identified four main paradoxes and these paradoxes need to be managed during digitalization of production systems (see Table 4). The identified paradoxes and core problems are intertwined, and it can be discussed if they are digital transformation or digitalization paradoxes. All paradoxes are related to way of working and decision making and can be viewed from a digital transformation or digitalization perspective.

The identified belonging paradox caused the problem with where should technological development be performed (local vs global development)? This is in line with Mishra, et al. [30] who discuss in terms of centralization vs decentralization. It seems that a combination of global and local development is needed to capture the local innovation capability and to develop a new technical solution that is transferable between production sites. Danneels and Viaene [12] describe this paradox as global strategy vs regional entrepreneurialism. The identified organizing paradox caused the problem with how should digitalization of productions system be performed (stage-gate vs agile process)? As a consequence, the tension is related to a controlled or flexible development process that needs to be managed. We see the identified problem and paradox of organizing as a way of working that needs to be organized affecting the other identified paradoxes of performing and learning. The identified performing paradox caused the problem with to what degree should digital technologies be standardized and transferable between production sites (standardization vs customization)? Mishra, et al. [30] categorizes standardization vs customization in their study text to the paradox of belonging while we see this this paradox affecting the development performance. The findings indicate that some sort of adaptation of digital technologies is needed during digitalization of production systems and degree of standardization is a major problem in both cases studied. The identified learning paradox caused the problem with how should technological knowledge be developed (learning before doing vs learning by doing)? Identified learning paradoxes in the literature focus more on culture, mindset, and radical

vs incremental change [11, 30, 32]. The identified learning paradox is intertwined with the organizing paradox that defines the way of working in the development process.

To summarize, all identified paradoxes have mutual relations and thereby affect each other. This dilemma causes another problem with where to start when dealing with the underlaying tensions to the paradoxes. Decisions need to be made when it comes to how the development process should look like, including where development should take place and by whom, and in the end manage the degree of standardization of technical solutions. Viewing the paradoxes from a digital transformation and digitalization perspective, the following aspects must be considered. From a digital transformation perspective as a bigger concept manufacturing companies need to set-up a supportive organizational structure, adapt development processes for digitalization, and appoint personnel for the actual work to be done, i.e., digitalization. From a digitalization perspective the identified problems and tensions occurred during digitalization of production systems and might still exist even though strategies for digitalization are available. Thus, the identified paradoxes are still a problem that needs to be dealt with at manufacturing companies.

5.1. Limitations and future research

Some important limitations of this study are worth mentioning. This study was conducted at two manufacturing companies from different types of industries and customers. There is a lack of best practice when it comes to digitalization of production systems. Insights from two digitalization projects of production systems have been studied, it still limits the possibility to generalize the findings to other contexts.

Accordingly, one suggestion for further research is to analyze paradoxes during digitalization of production systems in other types of industries and digital technology development projects. Another suggestion for future research is to validate the identified paradoxes in this paper as well as problems and tensions.

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References

[1] Sjödin DR, Parida V, Leksell M, Petrovic A. Smart Factory Implementation and Process Innovation: Research-Technology Management. 2018;61(5):22-31.
[2] Calabrese A, Dora M, Levialdi Ghiron N, Tiburzi L. Industry's 4.0 transformation process: how to start, where to aim, what to be aware of. Production Planning & Control. 2020:1-21, doi:10.1080/09537287.2020.1830315.
[3] Chen B, Wan J, Shu L, Li P, Mukherjee M, Yin B. Smart factory of industry 4.0: Key technologies, application case, and challenges. IEEE Access. 2017;6:6505-19, doi: 10.1109/ACCESS.2017.2783682.
[4] Stålberg L, Ericson Öberg A. Factory 4 Tomorrow Organization-Challenges and Enablers to Encourage Simultaneous Exploration and Exploitation. Advances in Transdisciplinary Engineering; 2022, doi:10.3233/ATDE220132.

[5] Castelo-Branco I, Cruz-Jesus F, Oliveira T. Assessing Industry 4.0 readiness in manufacturing: Evidence for the European Union. Computers in Industry. 2019;107:22-32, doi:10.1016/j.compind.2019.01.007.
[6] Pacchini APT, Lucato WC, Facchini F, Mummolo G. The degree of readiness for the implementation of Industry 4.0. Computers in Industry. 2019;113, doi:10.1016/j.compind.2019.103125.
[7] Ghobakhloo M. The future of manufacturing industry: a strategic roadmap toward Industry 4.0. Journal of Manufacturing Technology Management. 2018;29(6):910-936, doi:10.1108/JMTM-02-2018-0057
[8] Matt C, Hess T, Benlian A. Digital transformation strategies. Business & Information Systems Engineering. 2015;57(5):339-43.
[9] Vial G. Understanding digital transformation: A review and a research agenda. The Journal of Strategic Information Systems. 2019;28(2):118-44.
[10] Wang B. The future of manufacturing: a new perspective. Engineering. 2018;4(5):722-8, doi:10.1016/j.eng.2018.07.020.
[11] Dieste M, Sauer PC, Orzes G. Organizational tensions in industry 4.0 implementation: A paradox theory approach. International Journal of Production Economics. 2022:108532, doi:10.1016/j.ijpe.2022.108532.
[12] Danneels L, Viaene S. Identifying Digital Transformation Paradoxes: A Design Perspective. Business & Information Systems Engineering. 2022:1-18.
[13] Andriopoulos C, Lewis MW. Exploitation-Exploration Tensions and Organizational Ambidexterity: Managing Paradoxes of Innovation. Organization Science. 2009;20(4):696-717,829-30, doi:10.1287/orsc.1080.0406.
[14] Papachroni A, Heracleous L, Paroutis S. Organizational ambidexterity through the lens of paradox theory: Building a novel research agenda. The Journal of Applied Behavioral Science. 2015;51(1):71-93, doi:10.1177/00218863145531.
[15] Schad J, Lewis MW, Raisch S, Smith WK. Paradox research in management science: Looking back to move forward. Academy of Management Annals. 2016;10(1):5-64, doi:10.5465/19416520.2016.1162422.
[16] Lewis MW. Exploring paradox: Toward a more comprehensive guide. Academy of Management review. 2000;25(4):760-76, doi:10.5465/amr.2000.3707712.
[17] Smith W, Lewis M. Toward a theory of paradox: A dynamic equilibrium model of organizing. Academy of Management Review. 2011;36(2):381-403, doi: 10.5465/amr.2009.0223.
[18] Schad J, Lewis MW, Smith WK. Quo vadis, paradox? Centripetal and centrifugal forces in theory development. Strategic Organization. 2019;17(1):107-19, doi:10.1177/147612701878621.
[19] Gong C, Ribiere V. Developing a unified definition of digital transformation. Technovation. 2021;102:102217, doi:10.1016/j.technovation.2020.102217.
[20] Schallmo D, Williams CA, Boardman L. Digital transformation of business models-best practice, enablers, and roadmap. International Journal of Innovation Management. 2017;21(8), doi: 10.1142/S136391961740014X.
[21] Ahlskog M, Granlund A, Badasjane V, Bruch J, Sauter B. Approaching digital transformation in the manufacturing industry – challenges and differing views. Int J Manufacturing Research, 2023;18(4):415-433, doi:10.1504/IJMR.2023.135647.
[22] Savastano M, Amendola C, Bellini F, D'Ascenzo F. Contextual impacts on industrial processes brought by the digital transformation of manufacturing: a systematic review. Sustainability. 2019;11(3):891, doi:10.3390/su11030891.
[23] Ahlskog M, Bruch J, Jackson M. Factors affecting development of production technologies in a machining environment. Tools and Methods of Competitive Engineering 2014 TMCE 2014, 19-23 May 2014, Budapest, Hungary.
[24] Cocchi N, Dosi C, Vignoli M. Stage-Gate Hybridization Beyond Agile: Conceptual Review, Synthesis, and Research Agenda. Ieee Transactions on Engineering Management. 2023, doi: 10.1109/tem.2023.3282269.
[25] Brosseau D, Ebrahim S, Handscomb C, Thaker S. The journey to an agile organization. McKinsey & Company, May. 2019;10:14-27.
[26] Peeters T, Van De Voorde K, Paauwe J. The effects of working agile on team performance and engagement. Team Performance Management: An International Journal. 2022;28(1/2):61-78, doi:10.1108/TPM-07-2021-0049.
[27] Ahlskog M, Bruch J, Jackson M. Knowledge integration in manufacturing technology development. Journal of Manufacturing Technology Management. 2017;28(8):1035-54, doi: 10.1108/JMTM-03-2017-0051.
[28] Pisano GP. Learning-before-doing in the development of new process technology. Research Policy. 1996;25(7):1097-119, doi:10.1016/S0048-7333(96)00896-7.
[29] Maalouf M, Gammelgaard B. Managing paradoxical tensions during the implementation of lean capabilities for improvement. International Journal of Operations & Production Management. 2016;36(6):687-709, doi:10.1108/IJOPM-10-2014-0471.

[30] Mishra R, Singh RK, Song M. Managing tensions in resilience development: a paradox theory perspective on the role of digital transformation. Journal of Enterprise Information Management. 2022, doi:10.1108/JEIM-08-2022-0271.
[31] Carmine S, De Marchi V. Reviewing paradox theory in corporate sustainability toward a systems perspective. Journal of Business Ethics. 2023;184(1):139-58.
[32] Wimelius H, Mathiassen L, Holmström J, Keil M. A paradoxical perspective on technology renewal in digital transformation. Information systems journal. 2021;31(1):198-225, doi:10.1111/isj.12307.
[33] De Angelis R. Circular economy and paradox theory: A business model perspective. Journal of Cleaner Production. 2021;285:124823, doi:10.1016/j.jclepro.2020.124823.
[34] Erthal A, Marques L. Organisational culture in lean construction: managing paradoxes and dilemmas. Production Planning & Control. 2022;33(11):1078-96, doi:10.1080/09537287.2020.1843728.
[35] Nasim S, Sushil. Revisiting organizational change: exploring the paradox of managing continuity and change. Journal of Change Management. 2011;11(2):185-206, doi:10.1080/14697017.2010.538854.
[36] Waldman DA, Putnam LL, Miron-Spektor E, Siegel D. The role of paradox theory in decision making and management research. Organizational Behavior and Human Decision Processes. 2019;155:1-6, doi:10.1016/j.obhdp.2019.04.006.
[37] Karlsson C. Researching Operations Management: Routledge 2009 Book. 2009.
[38] Yin RK. Case study research: Design and methods: sage; 2009.
[39] Voss C, Tsikriktsis N, Frohlich M. Case research in operations management. International journal of operations & production management. 2002.
[40] Bruch J, Rösiö C, Granlund A, Johansson PE. Managing the core plant role-key prerequisites from an operations perspective. International Journal of Manufacturing Research. 2020;15(1):90-106, doi: 10.1504/IJMR.2020.105502.
[41] Granlund A, Rösiö, C., Bruch, J., & Johansson, P. E. Lead factory operationalisation and challenges. Production planning & control. 2019;30(2-3), doi.org/10.1080/09537287.2018.1534292.
[42] Badasjane V, Granlund A, Ahlskog M, Bruch J. Coordination of Digital Transformation in International Manufacturing Networks—Challenges and Coping Mechanisms from an Organizational Perspective. Sustainability. 2022;14(4 2204):1-21, doi.org/10.3390/su14042204.
[43] Luscher LS, Lewis M, Ingram A. The social construction of organizational change paradoxes. Journal of Organizational Change Management. 2006;19(4):491-502, doi:10.1108/09534810610676680.