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Towards Resilient and Sustainable Production Systems: A Research Agenda

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Abstract. To be competitive, it is widely recognized that manufacturing companies need attention on sustainability aspects. However, there is still a lack of knowledge about how to combine requirements on sustainability and profitability to achieve long-term competitive manufacturing. Furthermore, there is a need for knowledge on how to develop resilient and sustainable production systems. This paper aims to explore the state-of-the art and state-of-practice associated with development of resilient and sustainable production systems, with focus on challenges and enablers. To achieve the aim of the paper, a traditional literature review was carried out, combined with results from knowledge creation workshops with five manufacturing companies striving towards resilient and sustainable production systems. In the paper, initial results from a three-year research project are included. The research project aims at developing knowledge that can support development of resilient and sustainable production systems, including the value chain, for the future. The industrial relevance of the project lies in ensuring a future-proof adaptable factory in an efficient industrial value chain, based on circularity in terms of minimum waste and long-term overall sustainability with a triple bottom line perspective, including social, ecological, and long-term economic values.

Keywords. resilient production, sustainability, greenfield, brownfield, production development.

1. Introduction

Manufacturing is the backbone of Europe [1]. From a focus purely on competitiveness, via inclusion of sustainability, the ManuFUTURE 2030 vision now also includes resilient and adaptive manufacturing ecosystems. The importance of resilience and sustainability in combination with profitability is stressed in a recent report from EU (p. 3), presenting Industry 5.0, as a successor and complement to Industry 4.0. Industry 5.0 specifically recognizes the "power of industry to achieve societal goals beyond jobs and growth, to become a resilient provider of prosperity, by making production respect the boundaries

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of our planet and placing the wellbeing of the industrial worker at the centre of the production process" [2].

A decade ago, sustainability was identified as an emerging megatrend like quality and IT [3]. Today we can clearly see that this was a correct forecast; sustainability is now an essential part of the industrial strategy as formulated by the European Commission: "Through a twin transition to a green and digital economy, the ambition is to make the industry in Europe globally competitive". A parallel initiative with the ambition to make Europe climate neutral by 2050, is the European Green Deal [4], i.e., EU's new growth strategy, aiming at a fair and prosperous society, with a modern, resource-efficient, and competitive economy. Many European businesses want to contribute to the overarching purpose-driven vision and make a "difference in the world" and are thus paying attention to environmental and social components in the organisation and development processes [5]. As a response from the manufacturing industry, sustainable manufacturing has emerged as a concept and a practice, with the goal to preserve resources and at the same time contribute to economic growth and human welfare [6].

Manufacturing companies therefore need an agenda including sustainability perspectives, often implying a need to innovate and adapt their operations, integrating new competitive priorities. It is assumed that there is no trade-off between sustainability and profitability, but there is still a lack of knowledge about how to combine requirements on sustainability and profitability to achieve competitive manufacturing [7]. The best opportunity for a manufacturing company to consider aspects related to sustainability, resilience and profitability is during the development of a production system [8]. Production system development could refer to development and refinement of an existing production system, i.e., brownfield development, but it could also refer to greenfield development, e.g., development of an entirely new production plant. Production system development is often carried out as part of a product development project [9]. A limitation with current product development processes is however (still) the limited inclusion of aspects related to production system development [10]. In general, the production system development approach is often ad hoc, lacking systematic and long-term thinking [8, 11]. Development of production systems requires that a multitude of influencing factors are considered in parallel in a fast-moving surrounding, challenging the work. So far, there is limited research on how to develop resilient and sustainable production systems that contributes to the profitability for the manufacturing company.

This paper aims to explore the state-of-the art and state-of-practice associated with development of competitive, resilient, and sustainable production systems. A literature review was carried out, combined with empirical results from workshops with manufacturing companies striving towards resilient and sustainable production systems. Based on the identified challenges and enablers, a preliminary research agenda is outlined.

2. Research methods applied

The process of developing a research agenda included an overview of current state knowledge both in the literature and in practice. Details about the data collection is provided below. To support the analysis an analytical framework was applied, also described in this section.

As a foundation for the state-of-the art description, a traditional literature review was carried out [12]. The approach was selected to combine different sources, such as conference proceeding, scholarly journals, with EU reports and visions for Europe. As a starting point, an initial systematic literature search was done, to get an overview of recent research with focus on development of resilient and sustainable production systems. The search string "sustain* AND resilien* AND develop* AND production OR manufact*" gave 2057 hits in Scopus. This was narrowed down by filtering the result towards publications with focus on an industrial setting, resulting in 115 remaining papers, where the dominating journal was Sustainability (Switzerland) with ~18% of these papers. Based on a review of abstracts, 47 papers were included for full text reading, and about 50 percent of these were relevant. Since a limited number of papers were addressing both sustainability and resilient production or manufacturing development, additional searches were made. A snowballing approach was applied [13], resulting in several interesting and relevant publications for the purpose of this paper.

The industrial material involves perspectives from five companies, all of them industrial partners in a recently started research project. The selection of companies was based on the need to include representatives from the entire value chain in the research project. The industrial partners represent manufacturing companies, component suppliers, manufacturing equipment suppliers and construction project management. A brief overview of the involved companies is provided in table 1. Four of the five participating companies can be classified as small- or medium-sized (SME), according to EUs definition. An SMEs employ fewer than 250 persons and have an annual turnover not exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million. (http://data.europa.eu/eli/reco/2003/361/oj).

Table 1. Overview – industrial partners

Company	Description
Company Generations	Manufacturing company, greenfield and brownfield production projects
Company Planet	Manufacturing company, start-up, greenfield production project, SME
Company Turning	Manufacturing company, component supplier, brownfield production projects, SME
Company Automation	Automation solution supplier, supporting industrial production development (greenfield and brownfield production projects), SME
Company Project Management	Industrial consultant supporting organisations in different sectors with construction project management, SME

The research project applies an interactive research approach and thereby data collection started already during the project application phase, and the project scope was jointly formulated by practitioners and researchers [14]. The empirical data in this paper include perspectives risen during project activities such as workshops and other meetings carried out during the first six months of the research project. Most project activities were recorded, and detailed notes were taken.

In interactive research, workshops are an important collaboration arena and mean to reflect on, interpret, and develop joint knowledge with outcomes beneficial for both practitioners and researchers [15-17]. In this research project different type of workshops are included to capture the industrial companies' challenges/barriers and enablers related to development of resilient and sustainable production systems. The workshop typology, see Figure 1, developed for the research project, is based on the workshop focus (x-axis)

and the participants in the workshop (y-axis). Focus could be on development (i.e., analysis/problem-solving/innovation) or dissemination, and participants can be limited to project participants (internal) or include other participants (external). Based on this, four different types of workshops are applied in the research project: a) Knowledge creation workshop, b) Inspirational workshop, c) Result workshop, and d) Knowledge sharing workshop.

Focus of the workshop / Participants	Development (Analysis/problem-solving/innovation)	Dissemination
Internal (only project partners)	a) Knowledge creation workshop	c) Result workshop
External (beyond the project)	b) Inspirational workshop	d) Knowledge sharing workshop

Figure 1. Workshop typology applied in the research project.

Joint analysis and reflection, including problem-solving and innovation, are essential elements of interactive research [15, 18]. *Knowledge creation workshops* are key within the research project, involving one or several of the project partners. In addition, also with focus on analysis/problem-solving/innovation, inspirational workshops are arranged involving participants beyond the research project. The idea with *inspirational workshops* is to provide food-for-thought and as the denomination indicates, inspire the participants with insights from external sources. The other type of workshops, with focus on dissemination, can include internal or external participants. In a result workshop typically results are presented, refined, and validated internally among the project partners, whereas in a knowledge sharing workshop results are shared in a broader community.

Qualitative data requires a structured analysis process. The three steps: data condensation, data display, and drawing and verifying conclusions were applied [19]. To guide the analysis presented in this paper, a priori codes were selected, based on a well-established framework. Considering the production system as a socio-technical system calls for a holistic perspective, including people, technology, and organisation [8]. Therefore, the applied analytical framework includes the three dimensions: technology, organisation, and people. The technology, organisation, and people (TOP)-framework is commonly used when dealing with development of socio-technical systems [20]. The framework has become a classic in the analysis of barriers in management in socio-technical systems [21]. The people dimension is related to the people in the system, with focus on culture and human factors such as recruiting, training, and learning patterns. The organisation dimension is related to organisational structure and management processes and aspects related to roles, responsibilities, processes, leadership, strategy, goals, measurement, and control can be included. Finally, the technology dimension is related to tools, IT systems, machinery, etc.

3. Results from the literature review

In this sector current practice related to development of resilient and sustainable production systems is presented, based on a traditional literature study.

3.1. The brownfield and greenfield setting for production system development

As mentioned, this paper is a first step in a research project. The research project address both brownfield and greenfield settings for development of resilient and sustainable production systems. The terminology, brownfield and greenfield, stems from the area of urban development [22], which also is reflected in the lexical definitions in Oxford Learner´s Dictionaries. In Oxford Learner´s Dictionaries greenfield refers to "an area of land that has not yet had buildings on it, but for which building development may be planned" and in a similar way, brownfield refers to "an area of land in a city that was used by industry or for offices in the past and that may now be cleared for new building development". In a production system development perspective, a greenfield project implies a new production site or a new production system within an existing site. Whereas a brownfield project implies rebuilding or reorganizing an existing site. In a brownfield project, it might be relevant to consider reuse of already available assets. Furthermore, limitations from already existing production system must be considered [8].

3.2. Resilient and sustainable production systems

Resilience is a multifaceted concept, used in wide variety of fields [23]. Resilience has been conceptualized as a multi-dimensional concept, consisting of a) disruption absorption and b) recoverability [24]. In this paper we use the term resilience in production as the ability to change or adapt during times of stress, disruption, or uncertainty, in line with [22, 24, 25]. The concept can be applied on various levels, including a production system or an entire eco-system. A lot of research has been done related to strategic frameworks for improved business performance but resilience at operational level within manufacturing companies has received less attention [25].

The roots of sustainable production can be found in the concept sustainable development established through the Brundtland report in 1987 [26], adapting the triple bottom line perspective – social, environmental, and economic dimensions of sustainability. The triple bottom line forms a foundation in many papers, although not all aspects are explicitly addressed. Many papers on sustainable or green manufacturing focus solely on the environmental dimension. When a lean, more resource efficient production system is considered, an economic aspect is at least implicitly included (e.g. [27]). Social aspects are more seldom considered, although mentioned in relation to both sustainability and resilience as an important factor (e.g., [28]).

The Lowell Center for Sustainable Production (LCSP) [29], p. 448, defines sustainable production as "the creation of goods and services using processes and systems that are: non-polluting; conserving of energy and natural resources; economically viable; safe and healthful for workers, communities, and consumers; and, socially and creatively rewarding for all working people." A similar definition is provided by Garetti & Taisch [30], p. 85, who defines sustainable manufacturing as: "the ability to smartly use natural resources for manufacturing, by creating products and solutions that, thanks to new technology, regulatory measures and coherent social behaviours, are able to satisfy economical [sic], environmental and social objectives, thus preserving the environment, while continuing to improve the quality of human life." As we can see, both definitions include the three dimensions of sustainability: environmental, economic, and social. We can also note that in the first example, the definition concerns production, whereas the latter definition concerns manufacturing. Manufacturing is a broader term than production (i.e., the process of making goods), including all industrial

activities connected to the manufacturing chain. In this paper, focus is on the production system [30].

3.2.1. Development of resilient and sustainable production systems

A production system can be expected to support multiple generations of products, and therefore a long-term perspective is essential when developing production systems [8]. It is therefore relevant to consider the life-cycle of a production system. When talking about the life cycle, most often we refer to the life-cycle of the product produced. It is however equally important to consider the life-cycle of the production system. The life-cycle of the production system starts with the planning of system design and ends with the system termination, re-use or phase-out [31].When developing a sustainable production system, it is essential to include aspects related to the triple bottom line, and to convert the identified needs, via functional requirements, into relevant physical solutions [32]. The social dimension of sustainability is however least reported in literature, multifaceted challenging to operationalize especially in the manufacturing domain [28]. However important to consider in early development phases, parallel with the economic and ecological dimension, as it has significance for socially sustainable work, well-being and performance [33, 34]. Furthermore, the three dimensions of sustainability needs to be considered with a system perspective, also constantly over time, specifically relevant in a faster pace of change in the surrounding environment or within an organisation [34-36].

Development of a resilient production system requires knowledge on what critical events that might influence the production system. During the covid-19 pandemic, we have seen that an unforeseen major critical event in the society can cripple a large part of the manufacturing industry. Manufacturing companies have experienced vulnerability from several perspectives, e.g., in the supply chain, work force, etc. It is suggested that a resilient production is achieved through integration of strategic manufacturing paradigms, such as using agile and lean principles and tools in combination with ICT and manufacturing technologies [37]. In order to maintaining long-term sustainability, organizations must have, or develop, an ability to continuously adapt towards new upcoming sustainable needs, and here resilience traditionally has been used for describing this adaptability [38]. In this respect innovation capability is needed in organizations together with utilization of cutting-edge technologies such as information technology enabling proactive handling and advanced decision support [39]. One necessity for manufacturing resilience is flexibility, another necessity is the capability of innovation in development skills [40, 41]. The ability to manage flexibility is also identified as a key in balancing between robustness and innovation as the extreme needs of a complex system, whereas both are identified to contribute to resilience [42]. In a flexible manufacturing system, it is possible to define several sets of choice which support creation of flexibility, but there is a need for future actions to enhance resilience.

3.3. Challengers and enablers related to resilient and sustainable production

Developing resilient and sustainable production systems encounter both challenges and enablers [6, 43]. In the literature, challenges and enablers related to sustainable manufacturing or sustainable production are most often treated separate from challenges and enablers related to resilient production systems. Barriers that affect the work with sustainable manufacturing can for example be categorized into aspects related to

economic limitations lack of top management commitment, lack of knowledge, and lack of environmental data [6]. In addition, barriers related to the attitude towards sustainability concepts, power shortage, lack of funding, lack of awareness of customers interested in green products are mentioned [43].

Enablers for sustainable manufacturing include market pressure, government promotions and regulations, economic benefits, investment in innovation & technology, lowering manufacturing cost, improving quality, education and training system, attracting foreign direct investment, infrastructure facilities in transportation sector, and development in E-economy [43]. Partly related to enablers are drivers to work with sustainability for manufacturing companies. As one example, improved competitiveness, cost reduction, improved environmental image, meeting new customer/market demand, and comply with environmental regulations and standards was pointed out as environmental drivers [6].

In one study investigating the integration of lean, green, smart manufacturing and resilience in manufacturing, barriers such as lack of management involvement, lack of communication, legal restrictions, lack of time and resources, resistance to change, lack of planning, technological issues were mentioned among other things [41]. The same study also identified several drivers for the integration, such as for example competitiveness, risk management, business model innovation, cost reduction and profitability, corporate image, and manufacturing performance. In addition, critical success factors were identified, including communication, top management commitment, cooperation and collaboration, organizational change readiness, project management and training. To improve sustainability within a company, areas to focus on are implementation of processes that supports information exchange both internally and externally and the humans within an organisation by cohesion resilience, emphasizing the behavior of leaders and strengthen the organisational culture [34, 38].

4. Empirical results

4.1. Initial challenges among participating companies

As mentioned, the results presented in this paper originates from the initial phase of a research project, involving several industrial partners following an interactive research approach [15]. Joint problem formulation, a hallmark of interactive research, was applied during the research application process. The point of departure were two greenfield production projects, both with clear ambitions towards sustainability. As part of the joint problem formulation process, several meetings were held with the industrial partners, prospective industrial partners, and the researchers. As a result, the initial focus on greenfield production projects was complemented with brownfield production projects, and industrial partners representing different parts of the value chain (manufacturing companies, component suppliers, manufacturing equipment suppliers and construction project management). A project scope was agreed upon, addressing both greenfield and brownfield development of resilient and sustainable production systems, including aspects related to the value chain. The initial challenges identified among the participating companies were related to several different aspects, including technology, organisation, and people. Among the challenges related to technology was the question on how to balance flexibility and efficiency. It was also perceived as a challenge to build a new plant in stages, to build a highly upgradable production facility. Another

technology-oriented challenge was to build complete automation systems that connect production flows in factories, and to combine complexity with ease of use. Among the organisational challenges, development of strategies for short-term and long-term manufacturing was mentioned, as was the question on how to be in the forefront of sustainability approaches in brownfield production projects. Furthermore, challenges to secure top-notch sustainability work when investing in production, and ability to manage both small- and large-scale projects was identified. Systematic management, design, and further development in all project phases, was also mentioned as challenges, including both the organizational and people aspect. On an overall level, the challenge to constantly meet customer´s new demands were mentioned, as customer demands constantly change concerning ecological improvements.

4.2. Resilient and sustainable production

Another important staring point in the research project was the perception of what resilient and sustainable production entails, and how it can be achieved. During a knowledge creation workshop (see figure 1 for the workshop typology), several resilience aspects were identified, together with means to achieve resilience, see table 2. In a similar way, during the same knowledge creation workshop, aspects related to sustainability was identified, see table 3. The identified means (right column), presented in table 2 and table 3, are categorized according to the TOP-typology (technology (T), organisation (O), people (P)). The participating companies had partly similar perceptions.

Table 2. Resilience aspects in a production system

What is resilience in the production system?	Means to achieve resilience in the production system
Flexibility enabling rapid changes in the surrounding environment	Competence, redundance in critical competence (P)
Capability to change fast enough to survive	Customers from different industrial sectors (O)
Not vulnerability due to lack of competence	A network with partners and suppliers (O)
Ability to manage personal turnover, not vulnerable to lack of competence (attractive employer)	A standardized work method (O)
Manage to handle changes in required capacity	Connected facilities – considering data security aspects (T)
Capability to develop and change according to the preconditions	Adapt the effort to the situation (O)
Understand the need from the customer – dynamic work methods	Completely new ways of thinking, an ability to find radically new solutions (O)
Ability to quickly change/find solutions if there is minor/medium disruption in the logistics chain	Ability to manage both “known unkowns” and "unknown unknowns (P)
	Develop a problem-solving capacity in the company (O)
	Redundance in processes and systems (T)
	A broad and flexible product offering – adaptable to different customers and markets (O)

T=Technology; O=Organisation; P=People

One of the companies referred to the surrounding environment, our planet, when asked to define resilience. According to them resilience also was related to our planet, and how they as a manufacturing company interact with the surrounding environment.

Table 3. Sustainability aspects in the production system

What is sustainability in the production system?	Means to achieve sustainability in the production system
Ability to communicate how the selection of suppliers affect to climate footprint	Ability to evolve in line with external changes without causing significant footprints (O)
A good working environment for colleagues and partners	High innovation capacity (adapted to facilitate the development of innovations/new offerings) (P)
Minimum footprint without risking quality	Modularity, "build as with Lego" – parts that you can put together in different ways to meet different needs (T)
Circularity (for example, residual currents become a raw material for new products)	Choose projects that contributes to a sustainable society (O)
Climate-neutral transport/logistics chain	Reused instead of new material (T)
Good for people throughout the value chain	

T=Technology; O=Organisation; P=People

In addition, challenges, and enablers to achieve resilient and sustainable production systems was discussed during another knowledge creation workshop. Among the identified technology-related enablers was high degree of automation, connected facilities, and modular solutions. Organisation-related enablers was cross-case collaboration in the early design phases, and collaboration with customers and consumers. People-related enablers was education, employees with the right skill, work environment, and the use of information from different industries. Yet another enabler was increased insights into the importance of transition to a sustainable society. Among the challenges, organisation-related challenges were change aversion and too little time for strategic issues. A people-related barrier was lack of staff. Another obstacle mentioned was that customers and consumers who, despite demanding sustainability solutions, are not always willing to pay for sustainability.

5. Resilient and sustainable production – a research agenda

Development of production systems requires that a multitude of influencing factors are considered in parallel. When developing resilient and sustainable production systems, it is essential to be aware of both enabling and hindering (barriers) factors. The empirical studies pinpoint the need of increased insights and knowledge of interrelating factors and potential impact on resilience and sustainability. Furthermore, the importance of proactive approaches in design phases of greenfield and brownfield production development projects has been emphasised [34].

From the perspective of technology, enablers and barriers in practice were related to technological connections needed in the value chain and in a products life cycle, modularity, and material refinement and reuse. Literature points out the need of a life-cycle perspective both from a product and a production system perspective [7], as well as aspects related to manufacturing performance, logistics and its infrastructures.

From an organisational perspective, enablers and barriers in practice were related to understanding of future customer needs and requirements, collaborations needed both within and across organisations combined with a standardized and agile work organisation characterized by transparency, efficient communication and socially sustainable work and workplaces. This is in line with literature addressing barriers related to economic issues and lack of environmental data, however there were indications of future market pressure on sustainability as a rising trend [40].

Additionally, from the perspective of people, enablers and barriers in practice were related to insights of the companies overarching vision and mission, change readiness, new competences needed, redundancy in critical competence. Furthermore, enablers were inclusive and broad participation during changes and development work, a good and attractive working environment within and beyond the organisation and throughout the value chain. Considering the wide range of enablers and barriers, this study strengthens the need to have a system perspective on resilience and sustainability with a balanced approach on economic, ecological and social dimensions, as advocated in literature, e.g., [28].

5.1. Production system development for resilience and sustainability

Recently several comprehensive literature studies have been carried out, aiming at research agendas for sustainable manufacturing [30, 44, 45]. As one research cluster related to sustainable manufacturing, enabling technologies for sustainable manufacturing was addressed, including new production processes, advanced manufacturing technology and ICTs for manufacturing [30]. An overview of various research themes in sustainable manufacturing from 1999 to 2020 included [45]: sustainable planning and scheduling, sustainable supply chain, lean and environmental management, sustainable machining, decision making, sustainable Industry 4.0 and Lean and environmental management. An important aspect of sustainable manufacturing is the shift from an open-loop life-cycle perspective to a closed loop material flow system, described as the 6R-strategy (reduce, remanufacturing, reuse, redesign, recycling, recover) [46].

So far, aspects related to the work procedures for development of resilient and sustainable production systems seems to be limited. Focus has been on development of sustainable products or production processes. Furthermore, aspects related to resilience and sustainability are seldom included explicitly in the literature on production system development, with some exceptions. Hence, there is a need of a supporting framework considering the interrelated sustainability dimensions (economic, ecological, and social) together with an understanding of what aspects to consider creating prerequisites for resilience. Such supporting framework has the potential to support environmental management systems, quality, and work environment systems (e.g. ISO 9001 and 14001) [6]. It is also expected to support the development of companies' production systems, such as Toyota Production System (TPS), based on lean-based improvement programmes.

In a faster pace of change, increasing complexity, and parallel interdependent work processes during production development, there is an increased challenge of transparency and risks for suboptimizations and disturbances if a system perspective is lacking. Hence, to fend off future obstacles, close collaboration cross boarders both within and across organisations are enabling factors, supporting proactive, solution-oriented approaches transferring obstacles to opportunities during design phases of production systems [8, 34].

Furthermore, to maintain a competitive position, long-term production innovation capability is required, enabling continuous transformation of production capabilities and business processes to develop increased levels of flexibility, reconfigurability, and intelligence in production systems [47]. Increased production innovation capability can hence be a key enabler for resilient and sustainable production systems, continuously upgrading the system [48].

5.2. Elements of resilient and sustainable production systems

To support resilience in production, it is important to understand different types of flexibility. Emerging technologies, in combination with the increased digitalization, challenge the IT-infrastructure. The selection and configuration of technologies, interfaces and processes are important in the future Industry 4.0-inspired production systems are potential key elements, and need to be managed in relation to efficiency, productivity, and flexibility. Usually, social sustainability dimensions related to work, are commonly not a major concern in early development phases, nor in greenfield projects such as start-ups [34]. However, these elements may influence future possibilities of resilience in production as human resources, working conditions, support, and structures are necessary for operational excellence, innovativeness, rapid decision making, responsiveness, managing changes and increased complexity. Hence, supported in industry 5.0 that stress the need of taking a human-centered approach [2].

6. Discussion and conclusion

Based on the initial findings in the research project it is confirmed that development of a resilient and sustainable production system is a complex activity, requiring a holistic understanding and a system perspective. The literature as well as the industrial partners, representing different industrial segments, shared a view on challenges and enablers related to developing and maintaining resilient and sustainable production system. A need for a joint strategical vision that include technology (selection, development, and implementation), organization (structure, agility, management, stakeholder collaborations, work environment) and people (skills and competences, participation, innovation and creative collaborative culture, and change readiness) is needed, to achieve a resilient and sustainable production system effectively and efficiently. To sum up, some main areas for further research was pointed towards development of resilient and sustainable production systems:

- Work procedures for production system development including understanding of enablers and barriers, as well as understanding of potential disturbances, causing a need to be resilient.
- Elements of resilient and sustainable production systems and their interdependencies from a system perspective.
- Organisational learning during fast pace of change that promotes innovative and dynamic capability; stability and flexibility; and sustainable solutions.

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References

[1] M. H.-L. Group", "ManuFUTURE STRATEGIC RESEARCH AND INNOVATION AGENDA (SRIA) 2030," in *ManuFUTURE Implementation Support Group*, ed, 2019.

[2] M. Breque, L. De Nul, and A. Petridis, "Industry 5.0 - Towards a sustainable, human-centric and resilient European industry,," J. European Commission, Ed., ed, 2021.

[3] D. A. Lubin and D. C. Esty, "The Sustainability Imperative," *Harvard Business Review,* Article vol. 88, no. 5, pp. 42-50, 2010.

[4] E. Commission", "The European Green Deal," ed: COM(2019) 640 final, 2019.

[5] N. Bosma, S. Hill, A. Ionescu-Somers, D. Kelley, J. Levie, and A. Tarnawa, "Global Entrepreneurship Monitor, Global Report, 2019/2020.," 2020.

[6] G. Johansson, E. Sundin, and M. Wiktorsson, *Sustainable Manufacturing*. Lund: Studentlitteratur, 2019.

[7] C. G. Machado, E. Pinheiro de Lima, S. E. Gouvea da Costa, J. J. Angelis, and R. A. Mattioda, "Framing maturity based on sustainable operations management principles," *International Journal of Production Economics,* vol. 190, pp. 3-21, 2017, doi: 10.1016/j.ijpe.2017.01.020.

[8] M. Bellgran and K. Säfsten, *Production Development: Design and Operation of Production Systems*. Springer, 2010.

[9] R. Salim, "Exploring the content and process of automation decisions in manufacturing system development projects: A study in the Swedish wood products industry," JTH Dissertation Series, 2021.

[10] F. Henriksson and J. Detterfelt, "Production – as seen from product development: A theoretical review of how established product development process models address the production system," presented at the NordDesign 2018 August 14 – 17, 2018.

[11] J. Bruch and M. Bellgran, "Integrated portfolio planning of products and production systems," *Journal of Manufacturing Technology Management,* 2014.

[12] J. K. Jesson, L. Matheson, and F. Lacey, *Doing your literature review: traditional and systematic techniques.* London: SAGE Publications, 2011.

[13] C. Wohlin, "Guidelines for snowballing in systematic literature studies and a replication in software engineering," presented at the Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering - EASE '14, 2014.

[14] L. Svensson, P.-E. Ellström, and G. Brulin, "Introduction – on Interactive Research," *International Journal of Action Research,* vol. 3, no. 3, pp. 233–249, 2007.

[15] M. Berglund, U. Harlin, and K. Säfsten, "Interactive research in production start-up—application and outcomes," *Journal of Manufacturing Technology Management,* vol. 31, no. 8, pp. 1561-1581, 2020.

[16] P.-E. Ellström, M. Elg, A. Wallo, M. Berglund, and H. Kock, "Interactive research: concepts, contributions and challenges," *Journal of Manufacturing Technology Management,* vol. 31, no. 8, pp. 1517-1537, 2020.

[17] K. Säfsten and M. Gustavsson, *Research methodology for engineers and other problem-solvers*. Lund: Studentlitteratur, 2020.

[18] K. Safsten and G. Johansson, "Guest editorial," *Journal of Manufacturing Technology Management,* vol. 31, no. 8, pp. 1509-1515, 2020, doi: 10.1108/jmtm-12-2020-462.

[19] M. B. Miles, A. M. Huberman, and J. Saldaña, *Qualitative data analysis: an expanded sourcebook* 4ed. Thousand Oaks: SAGE Publications, 2019.

[20] D. Brandt and E. Hartmannand, "<Hartmann & Brandt (1999)_SICI)1520-6564(199922)9 3 241 AID-HFM1 3.0.CO;2-B.pdf>," *Human Factors and Ergonomics in Manufacturing,* vol. 9, no. 3, pp. 241–243, 1999.

[21] D. Stenholm and D. Bergsjö, "Barriers to reuse of codified engineering knowledge
in product development – a literature review," *International Journal of Product Lifecycle Management,* vol. 12, no. 4, pp. 307-328, 2020.

[22] D. Nåfors, "On Brownfield Factory Layout Planning," in "Licentiate thesis at Chalmers University of Technology. Report no IMS-2019-20.," Department of Industrial and Materials Science Chalmers University of Technology., 2019.

[23] R. Bhamra, S. Dani, and K. Burnard, "Resilience: the concept, a literature review and future directions," *International Journal of Production Research,* vol. 49, no. 18, pp. 5375-5393, 2011.

[24] D. Essuman, N. Boso, and J. Annan, "Operational resilience, disruption, and efficiency: Conceptual and empirical analyses," *Int J Prod Econ,* vol. 229, p. 107762, Nov 2020, doi: 10.1016/j.ijpe.2020.107762.

[25] A. Thomas, D. Truong Pham, M. Francis, and R. Fisher, "Creating resilient and sustainable manufacturing businesses – a conceptual fitness model," *International Journal of Production Research,* vol. 53, no. 13, pp. 3934-3946, 2015, doi: DOI: 10.1080/00207543.2014.975850.

[26] G. Bruntland, "Our common future," *The World Commission on Environment 1 and Development,* pp. 45-65, 1987.

[27] S. Rahimifard *et al.*, "Forging New Frontiers in Sustainable Food Manufacturing," in *Sustainable Design and Manufacturing 2017*, Cham, G. Campana, R. J. Howlett, R. Setchi, and B. Cimatti, Eds., 2017// 2017: Springer International Publishing, pp. 13-24.
[28] J. W. Sutherland *et al.*, "The role of manufacturing in affecting the social dimension of sustainability," *CIRP Annals,* vol. 65, no. 2, pp. 689-712, 2016.
[29] V. Veleva and M. Ellenbecker, "Indicators of sustainable production: framework and methodology," *Journal of Cleaner Production 9 (2001)* vol. 9, pp. 519–549, 2001.
[30] M. Garetti and M. Taisch, "Sustainable manufacturing: trends and research challenges," *Production Planning & Control,* vol. 23, no. 2-3, pp. 83-104, 2012, doi: 10.1080/09537287.2011.591619.
[31] M. Wiktorsson, "Performance assessment of assembly systems," *KTH, Institutionen för produktionssystem,* 2000.
[32] D. S. Cochran and E. Rauch, "Sustainable Enterprise Design 4.0: Addressing Industry 4.0 Technologies from the Perspective of Sustainability," *Procedia Manufacturing,* vol. 51, pp. 1237-1244, 2020, doi: 10.1016/j.promfg.2020.10.173.
[33] K. Nielsen, M. B. Nielsen, C. Ogbonnaya, M. Känsälä, E. Saari, and K. Isaksson, "Workplace resources to improve both employee well-being and performance: A systematic review and meta-analysis," *Work & Stress,* vol. 31, no. 2, pp. 101-120, 2017.
[34] U. Harlin and M. Berglund, "Designing for sustainable work during industrial startups—the case of a high-growth entrepreneurial firm," *Small Business Economics,* vol. 57, no. 2, pp. 807-819, 2021.
[35] T. Backström, F. M. van Eijnatten, and M. Kira, "A complexity perspective," in *Creating Sustainable Work Systems - Emerging perspectives and practice*, P. Docherty, J. Forslin, and S. A. B. (Rami) Eds. London and New York: Routlegde. Taylor and Francis Group, 2002, ch. 6, pp. 65-75.
[36] K. J. Zink, "Designing sustainable work systems: The need for a systems approach," *Applied Ergonomics,* vol. 45, no. 1, pp. 126-132, 2014/01/01/ 2014, doi: https://doi.org/10.1016/j.apergo.2013.03.023.
[37] D. T. Pham, P. T. N. Pham, and A. J. Thomas, "Integrated Production Machines and Systems – Beyond Lean Manufacturing," *Journal of Manufacturing Technology Management* vol. 19, no. 6, pp. 695–711, 2008.
[38] A. A. A. Souza, M. F. R. Alves, N. Macini, L. O. Cezarino, and L. B. Liboni, "Resilience for sustainability as an eco-capability," *International Journal of Climate Change Strategies and Management,* vol. 9, no. 5, pp. 581-599, 2017, doi: 10.1108/ijccsm-09-2016-0144.
[39] S. Larsson, U. Harlin, S. Winzenburg, and A. Edström, "Färdplan: Teknik, material och förmågor för hållbar industriell konkurrenskraft. ," in "RISE report 2020:46," 2020.
[40] O. Khan, M. Christopher, and A. Creazza, "Aligning Product Design with the Supply Chain: A Case Study," *Supply Chain Management: An International Journal* vol. 17, no. 3, pp. 323–336, 2012.
[41] K. Johansen, "Challenges for Manufacturers when Customers are Locked Down: Is it Possible to be Prepared?," *The Journal of Applied Economics and Business Research,* vol. 10, no. 2, pp. 54-58, 2020.
[42] V. Asokan, M. Yarime, and M. Esteban, "Introducing Flexibility to Complex, Resilient Socio-Ecological Systems: A Comparative Analysis of Economics, Flexible Manufacturing Systems, Evolutionary Biology, and Supply Chain Management," *Sustainability,* vol. 9, no. 7, 2017, doi: 10.3390/su9071091.
[43] N. Bhanot, P. V. Rao, and S. G. Deshmukh, "Enablers and Barriers of Sustainable Manufacturing: Results from a Survey of Researchers and Industry Professionals," *Procedia CIRP,* vol. 29, pp. 562-567, 2015, doi: 10.1016/j.procir.2015.01.036.
[44] J. Malek and T. N. Desai, "A systematic literature review to map literature focus of sustainable manufacturing," *Journal of Cleaner Production,* vol. 256, 2020, doi: 10.1016/j.jclepro.2020.120345.
[45] A. Jamwal, R. Agrawal, M. Sharma, A. Kumar, S. Luthra, and S. Pongsakornrungsilp, "Two decades of research trends and transformations in manufacturing sustainability: a systematic literature review and future research agenda," *Production Engineering,* 2021, doi: 10.1007/s11740-021-01081-z.
[46] A. Huang and F. Badurdeen, "Metrics-based approach to evaluate sustainable manufacturing performance at the production line and plant levels," *Journal of Cleaner Production,* vol. 192, pp. 462-476, 2018.
[47] L. Larsson, "A Conceptual Framework for Production Innovation," Luleå University of Technology, 2020.
[48] D. Romero, J. Stahre, L. Larsson, and A. O. Ronnback, "Building Manufacturing Resilience through Production Innovation," presented at the 2021 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), 2021.