CONFERENCE ON PRODUCTION SYSTEMS AND LOGISTICS
CPSL 2021

2nd Conference on Production Systems and Logistics

Production Planning And Control In Distributed And Networked Open Production Sites – An Integrative Literature Review

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Abstract

The COVID-19 pandemic has once again drastically highlighted the trend and need towards urban and distributed production in cities (so-called Fab Cities) and their importance for society in order to independently meet the demand for physical goods. For small but highly individualized products, the manufacturing process is now possible in distributed and open production sites (so called FabLabs) equipped with digital manufacturing machines. These places empower individuals, start-ups, SMEs or companies to innovate, produce and educate. However, many open production sites are operated independently of each other, reducing resource efficiency, capacity utilization and competitiveness. This strives against the trend of physical and digital networking, which the manufacturing industry has long since completed in order to use its capacities more efficiently. In this paper, an integrative literature review is used to hypothesize and verify that such production planning and control (PPC) for open, distributed and bottom-up controlled production networks has not yet been scientifically researched. As a result of the review, it appears that today's production can be divided into three main types. The first main type represents the closed factory with its own PPC. The second main type represents globally connected and distributed value networks (e.g., Industry 4.0, cloud manufacturing) that are controlled top-down. The third and largely unexplored main type consists of open, bottom-up controlled as well as locally distributed but globally connected open production sites. To increase the future competitiveness and resilience of a sustainable Fab City, the authors show that further research is needed on the controlling and governance of open and urban production sites which the authors present in a research agenda.

Keywords

Production planning and control; Production network; Cloud manufacturing; Decentralization; Fab City

1. Introduction

The COVID-19 pandemic has highlighted the fragility of the current production system in unprecedented situations of global shortages in the medical, protective equipment and other industries. This is the result of globalized value chains in which physical products are manufactured and then transported across the globe. This can be problematic: The medical and protective equipment sector was drastically curtailed in the Asian region in the spring of 2020 due to COVID-19, which resulted in supply shortages of face masks, respiratory equipment and face shields. [1,2] In response, individuals and makers began to develop protection products (e.g., personal protective equipment) as part of globally networked online communities, shared knowledge and subsequently manufactured them in open production sites (FabLabs or OpenLabs). FabLabs or

DOI: https://doi.org/10.15488/11292 publish-Ing.

OpenLabs are production sites equipped with professional and digital manufacturing infrastructure (e.g., 3D printers, CNC mills) that are open to the public. As a result, such places basically offer the possibility of producing smaller everyday objects in a resilient manner on a small scale. [3-5] Some of the products manufactured there have even been officially approved and have thus made a real contribution to overcoming the pandemic. [6,7]

What could be exemplarily tested and successfully implemented during the pandemic is part of a new and global trend since 2011, which can be summarized under the term "Fab City". This concept comprises digital networking and the open exchange of product data (e.g., design files, bill of materials) and knowledge between cities (Fab Cities) within the network. As a result, all cities that are part of this network have access to the data and knowledge, which, in combination with publicly accessible, local and distributed production sites, enables them to physically manufacture a product. Cities are thus globally connected and locally productive. [8] Due to the topicality of the issue, public attention regarding this topic is increasing.

However, distributed manufacturing within a city is not as simple as might be imagined. Many FabLabs in Fab Cities are operated independently, which has a negative impact with regarding to resource efficiency and in competition with industrial value creation models. In order to make a relevant contribution to the supply of a city with physical products and to reduce the effects of global and ecologically unsustainable transportation chains, the goal should be to increase the efficiency and productivity of the individual open production sites by networking and controlling these decentralized production capacities analogously to the manufacturing industry. Through such control of the decentralized FabLabs, it would be possible to systematically capture demands from the city, pass it on to available makers and machines and produce locally. But how can production be planned and controlled in a city with such diverse actors, and what approaches already exist in this field? We hypothesize that such suitable, open and transparent production planning and control (PPC) systems that connect the needs of individuals, SMEs, startups and other actors with the local and distributed manufacturing capacities in the city do not currently exist.

In this paper, our objective is to examine this hypothesis. As a method, we use an integrative literature review. By doing so, we aim to determine the current state of literature on the topic. Due to the topicality of the subject in the field of decentralized and local production, there are currently many new publications. Therefore, we aim to analyze the state of the literature in the area of production planning and control in networks and check whether our hypothesis, that there is no PPC for Fab Cities yet, is true. In this paper, we first present the methodology and an overview of the literature. In the second step, we discuss the main results and, building on this, we present a research agenda in the third step.

2. Methodology

An integrative literature review includes and critiques previously published findings on a complex topic to gain a deeper understanding and new insights. [9,10]. We follow the approach of Torraco [10] and built our research in two steps: identifying and collecting papers via a keyword search in a database that are most representative regarding the topic, and then briefly defining and reviewing the keywords and analyzing the theoretical basis.

As a database we have used Web of Science. Web of Science offers up to 10 different sub-databases to choose from, which can be searched for specific terms. It is possible to filter by source type and discipline. In total, Web of Science lists over 21,100 journals, over 180,000 conference proceedings and over 80,000 books. The keywords were selected through a preliminary research. They represent the subject area of production planning and control, which primarily deals with individual factories, as well as the extended production planning and control in networks through the more general terms "Production Networks" and "Cloud Manufacturing".

In the course of the keyword search, a large selection of literature was found in the database, thus, the selection of results was further limited using filters. For this purpose, on the one hand, the exact and coherent word group of the individual keyword was searched for, and, on the other hand, the condition that the keyword had to be listed in the title or abstract of the respective paper was introduced. This significantly reduced the number of results. (see Figure 1)

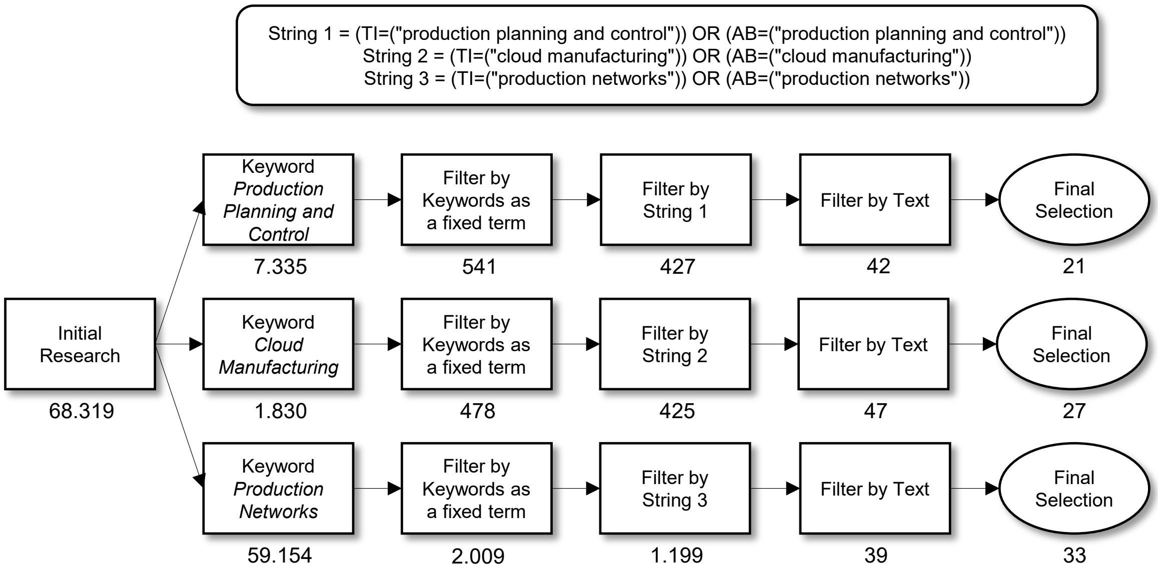

Figure 1: Literature selection process

In the further procedure of literature selection, the title and abstract of each result were considered as a first step. As a second step, the paper was read in full and, if relevant, the central statements and aspects were elaborated, and the sources in the bibliography and the quality of the journal were checked. In particular, the selection process discarded literature that had no overlap with the present work in the title or abstract. Furthermore, literature that was not peer-reviewed and/or controlled by a publisher was excluded.

In the following, the results of the literature research are presented. First, all three keywords are defined for this purpose based on the statements of the selected literature (chapter 3). This is followed by an analysis of the individual papers (chapter 4). Finally, the main findings (chapter 5) and the research agenda (chapter 6) are presented.

3. Keyword definition

3.1 Production Planning and Control (PPC)

In a manufacturing company, the PPC is responsible for planning and controlling a manufacturing process in terms of schedules, capacities and output. [11,12] The PPC converts a customer order into a physical product. [13] It is thus essential for meeting customer requirements regarding production parameters and can therefore be found in different areas of a company and in various designs. [14,15] Typical functions of a PPC include demand planning, demand control, capacity planning and order planning. The main objectives of these functions are to reduce work-in-process, reduce lead times, reduce inventory costs, improve responsiveness to changes in demand and meet delivery deadlines. [15] The systems are basically hierarchical and top-down. [13,16]

The use of PPC has changed a lot over the years. In the past, they were very static and only insufficiently considered changes from the current situation (real-time representation). [17-19] Today's factories, in contrast, require agile, scalable and reconfigurable production systems. [11,20] For this purpose, the integration of the Internet of Things (IoT) and further sensor technology is promising. [16,21] Furthermore, since about 2005, production has increasingly been "make-to-order", meaning a product (or a part of it) is not manufactured until the customer order has been received, so that essential product features can still be adapted to customer needs. [22]

3.2 Cloud Manufacturing (CMfg)

Conventional PPC is not sufficient for distributed production. Due to globalized value chains, extensive networking in production is necessary which can be achieved by CMfg. [23] Although there is no unified definition for this term, it basically refers to the principle of cloud computing in the manufacturing world. [24,25] CMfg is a service- and demand-oriented production approach in networks, where configurable production resources and capacities can be accessed in real time via the Internet. [26-28] This means that production resources and capacities are virtualized and can thus be accessed by any user. [29] The concept aims to circulate capacities and to realize demand-driven utilization of various production resources and capacities. This is done by providing reliable, high-quality, cost-effective and demand-driven manufacturing services for the entire manufacturing life cycle. [27,30]

Production can thus take place in a distributed manner, while all the necessary services and knowledge (e.g., production data, scheduling, business workflow management) of the network are stored centrally in a cloud. Additionally, any organization or individual should be able to participate in the network and share knowledge in the cloud, similar to Wikipedia. [24,27] The technical implementation is supported in the physical and virtual domains by IoT, cloud computing and other computing technologies. [27,31]

There are three different roles in CMfg. The provider offers and owns the production capacities in the respective production. The operator runs the platform and thus provides services in the cloud for all users. The consumers are the subscribers of the platform who buy manufacturing cloud services from the operator. [27] Whether anyone (e.g., individuals or OEMs) or only business partners can be consumers or providers is handled differently. [32,33] However, unlike Industrie 4.0, CMfg is fundamentally not seen as a purely industrial concept but is usually implemented that way. [34,35]

3.3 Production Networks (PN)

Production Networks (PN) or Global Production Networks (GPN) are organized networks in an area, consisting of a company and non-company institutions, through which goods and services are produced and distributed. [36,37] For the joint production of these goods and services, all activities in the network are combined and shared. [38]

The network benefits from this division because the modern economy consists of networked and specialized production units that share knowledge and with complementary capabilities in each unit allow the whole network to cover a wider range of capabilities. [39,40] As a result, production networks provide rapid and cost-effective access to resources, skills and knowledge, reducing transaction costs for each network partner and enabling the network as a whole to respond more quickly to market trends. [40-43]

Production networks are very dynamic and variable due to constant external changes [36], but at the same time they are very stable in the long term and have a polycentric hierarchical structure. [44] Unlike global commodity chains and global value chains, production networks do not have a linear structure. Instead, all possible network configurations between network partners are allowed, making the classical customer-supplier relationship obsolete. [36,44] Companies are the main active partners in production networks, but theoretically all relevant actors and relationships are addressed, which, however, is usually not the case in practice. [36,40,45]

4. Literature review

After defining the three keywords according to the selected literature, the analysis of the literature follows below. A total of 81 papers are evaluated in this review. The chronological sequence of publications clearly shows that the majority of publications was published after 2010. This is due to the novelty of the concepts, which were first made possible by technological progress (e.g., cloud computing, IoT, ICT). The classic PPC has been around for a longer time and is well established in the manufacturing sector. (see Figure 2)

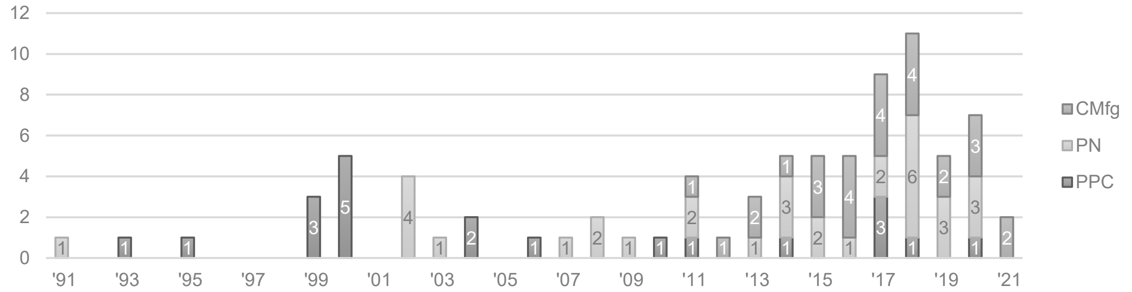

Figure 2: Chronological representation of the publications for the individual keywords

The main statements were extracted from the selected literature and evaluated in terms of accessibility, networking and decentralization. It was found that although many authors from the various approaches describe or strive for (global) networking, these networks are mostly closed or limited to a specific group of users. In particular, economic networks within companies and industries were described. Globally networked production systems with accessibility for everyone (individuals, SMEs, startups, companies, ...) could only be recognized in rudimentary form in exceptional cases. (see Figure 3)

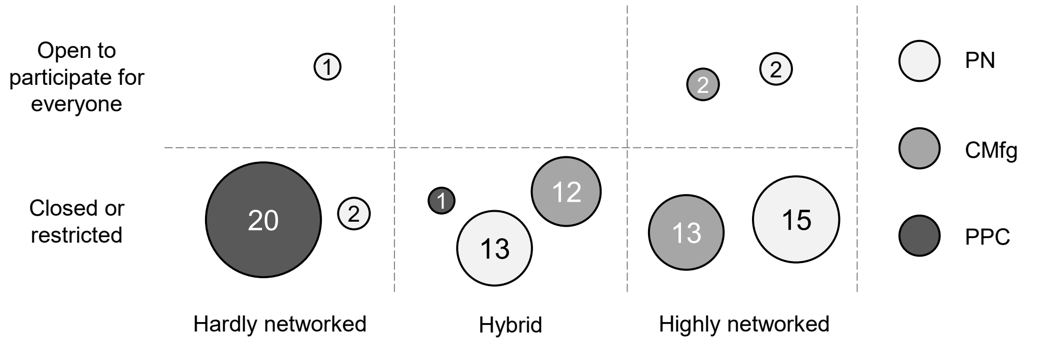

Figure 3: Categorization of papers according to openness and connectedness

The situation is similar regarding the decentralization of the individual sites (both global and local). Here, too, it can be seen that the majority of authors describe or strive for decentralization of the sites, but opening up this production network to outsiders is also not described or strived for in the vast majority of cases. (see Figure 4)

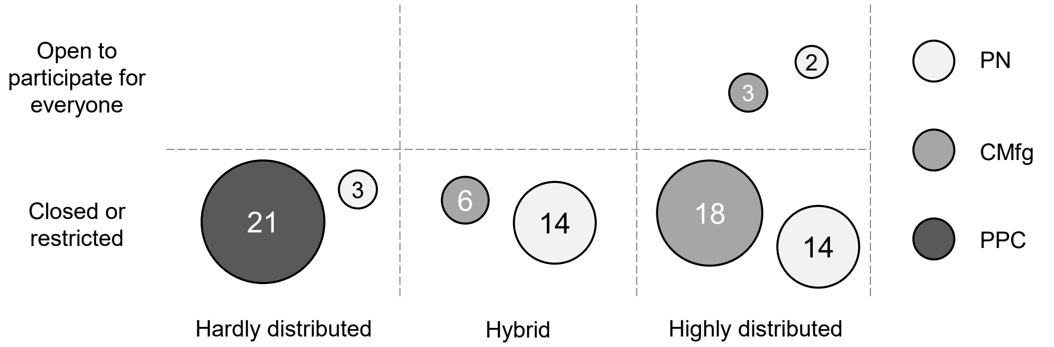

Figure 4: Categorization of papers according to openness and distributivity

The papers were published in various journals covering a range of different disciplines. However, the majority is focused on the field of production engineering. Since the topic is fundamentally interdisciplinary, additional disciplines could also be identified. The following table shows all journals including the editors who published at least two papers mentioned in this review. (see Table 1)

Table 1: Journals with more than one paper in this review

Journal	Total counts	Publisher	Discipline	Impact Factor
Production Planning & Control	8	Taylor & Francis	Operations management	4.22
The International Journal of Advanced Manufacturing Technology	6	Springer	Manufacturing Technology	2.96
International Journal of Production Research	6	Taylor & Francis	Production Engineering	4.58
International Journal of Computer Integrated Manufacturing	5	Taylor & Francis	Engineering	2.48
Journal of Economic Geography	3	Oxford Academic	Economic geography	3.29
Journal of Manufacturing Science and Engineering	3	ASME	Manufacturing Technology	2.88
CIRP Annals	2	Elsevier	Manufacturing Technology	5.52
IEEE Access	2	IEEE	Multidisciplinary	4.64
CIRP Journal of Manufacturing Science and Technology	2	Elsevier	Manufacturing Technology	3.26
Regional Studies	2	Taylor & Francis	Urban and regional change	3.34
Research Policy	2	Elsevier	Management and Technology Science	5.35

Most of the contributions present an overview and basics on the respective topic. Since PPC has already been an established tool in production for years, the authors here deal in particular with the simulation, modeling and flexibilization of production and the presentation of new concepts. Regarding cloud manufacturing, the main focus is on presenting the basics of the concept. Since the concept is still quite new (first mentioned in 2009), mainly theoretical approaches are described. Not much is published on the implementation or analysis of existing networks. This is in contrast to production networks, for which there is a detailed analysis of practical implementation and realization. Apart from this, the basics are also presented here. There are only a few publications on the integration of customers in the product development process and on production in maker networks. And although the topic of sustainability has become ubiquitous in recent years, only two authors of the selected papers analyzed effects of production networks on ecology. (see Table 2)

Table 2: Main categories of papers by keywords

Keyword	Topic	Reference
Production Planning and Control	Flexibilization	[13,20,46,47]
	Increase of efficiency or production	[48]
	Real-time production	[49,50]
	Framework	[51]
	Modeling and simulation	[14,17,19,22,52,]
	Conceptualization	[16,53–57]
	Implementation	[58,59]
Cloud Manufacturing	Basics and overview	[25,27,29,31,35,60.61]
	Modeling and Simulation	[26,62,63]
	Optimization and increase of efficiency	[64–67]
	Implementation	[68]
	Future perspectives	[23,24,33,34]
	Real-time production	[69]
	Dynamization	[28]
	Surveys and studies	[70,71]
	Collaborations	[72]
Production Networks	Analysis of networks	[45,73–78]
	Influences on networks	[79,80]
	Surveys and studies	[81,82]
	Increase of efficiency or production	[83]
	Customer integration	[84,85]
	Basics and overview	[36,38,39,44,86-93]
	Production Planning and Control	[94]
	Sustainability	[95,96]
	Flexibilization	[97]
	Knowledge Management in Networks	[40,98]

5. Results

Based on the definitions and the analysis, we identified essentially three relevant main types of production, which differ massively in terms of their accessibility, distribution and degree of connectedness. Moreover, the actors in the main types are very different.

Main type 1 represents **closed production processes** within a company which are hardly or not networked and distributed. These are production companies that produce at one location and are controlled by a central PPC. In these companies, it is top-down specified which production step has to be carried out at which point in time, by whom and in which sequence. There is no provision for opening up the production to external parties. Examples of such companies are traditional manufacturing SMEs in Germany. There are many publications about the main type 1.

Main type 2 represents (largely) **closed but highly networked and distributed** companies with several production sites or a network of several companies with distributed production sites. In these primarily commercially oriented networks, a central body dictates which production step is to be carried out when, where and by whom. Opening up to outsiders is largely only intended if they can improve the efficiency of the network through additional production capacities. This primarily addresses other companies. Opening up to individuals is generally not intended. In addition, decisions in these networks are also top-down driven. Producers (companies and employees) are not involved in the decision-making process. Due to the great distances between locations in globally distributed production, additional logistical effort is required. Examples of such companies can be found in the traditional supplier industry (e.g., automotive and aircraft industry), where large corporations (e.g., VW, Airbus) stipulate the specifications for the production centrally and have them implemented globally. There is an increasing amount of literature on this main type.

Main type 3 represents **openly accessible, networked and distributed production** opportunities and sites that are accessible to everyone and address different actors (e.g., individuals, SMEs, startups, companies) in terms of production, innovation and education due to the number and professionalism of the machines. [3,82] These production sites (FabLabs or OpenLabs) and smaller factories can be embedded in the urban environment due to their small size as well as low noise pollution and emission levels, allowing cities to produce again at the point of need. Networks with open production sites offer society the opportunity to participate in and co-determine value creation again. [99-101]

6. Research Agenda

As this review shows and as it was hypothesized in the introduction, there are currently very few publications on production planning and control in open, distributed and networked production sites that are simultaneously controlled by the entire network (bottom-up). Based on the social, economic and environmental potentials that are already described in the literature in the areas of production, innovation and education (e.g., applied STEM education for youth, commercial use by artisans to individualize products, prototyping by SMEs and startups, manufacturing of PPE during COVID-19 pandemic), we see a need for further research on production planning and control of open, networked, and distributed production sites in order to promote this specific main type and build a new resilient and competitive production system. Specifically, we recommend the following three sequential research steps:

1 **Analysis of the current state** in open production sites with regard to the machines and social networks as well as the local and global networking of the individual sites. To learn more about this current state, we propose an analysis of the states in different Fab Cities. The individual Fab Cities can be seen as contexts and cases in which new insights can be created by means of interviews, participant observation and existing production data, which can serve as the basis for an urban production planning and control system (step 2).

2 **Derivation of research work** in terms of modeling and simulation for the planning and control of such an open and dynamic production network. Modeling and simulation are carried out on the basis of the knowledge gained in the first step. This enables analyses in terms of increasing efficiency, productivity and profitability, which underline the added values for the urban stakeholders through an urban and decentralized production planning and controlling system.

3 **Exemplary implementation** of such a system in a production network with subsequent field tests to research the practical suitability of such a production system. The implementation is carried out in the analyzed cities, providing a match between simulation and reality, so that the practical benefits can be evaluated and confirmed by a PPC in open and distributed production networks.

7. Conclusion

The COVID-19 pandemic has shown how important resilient and locally embedded but globally connected production sites are in order to share data globally and produce products locally. But it has also been shown that the efficiency and penetration of the networks have been mediocre because the joint activities have been poorly planned and managed. We therefore hypothesized that there is still no suitable production planning and control system for such production to be found in the body of literature.

To test this hypothesis, we conducted an integrative literature review including 81 papers. We found that there are three main types of production forms under the keywords "Production Planning and Control", "Cloud Manufacturing" and "Production Networks", which differ significantly in terms of their openness, distribution and networking.

- **Main type 1** represents closed and local production within a company.
- **Main type 2** represents closed and economic networks with local and global distribution and connections, which cannot be used by outsiders.
- **Main type 3** represents an open, distributed and networked production system for everyone.

Main type 3 addresses the needs of all actors (individuals, SMEs, startups, companies) through the number and professionalism of machines. In this respect, there is very little literature on the planning and controlling of such a network. Therefore, we can confirm the hypothesis through the integrative literature review.

We see a need for further research in the area of production planning and control in open, distributed and networked production sites to promote the development of a resilient, new and competitive manufacturing field. Specifically, we recommend that researchers in the field of production engineering survey the current state in such networks in order to model and simulate a PPC system and then implement it in a network as an example and study it within the framework of a field test.

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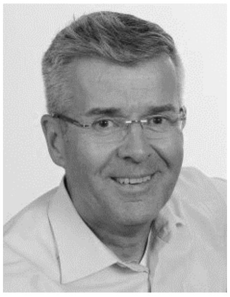

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