Digital Platforms in Manufacturing: Past, Present and Future

Xiaolong Bai [1, *]

[1]School of Management, University of Liverpool, Liverpool, England

*Corresponding author: hsxbai7@liverpool.ac.uk

Abstract. In this paper, we conducted a literature review of manufacturing and digital platform, examining 92 articles published between 1997 and 2022. In our study of the literature, we used the software HistCite and VOSviewer to conduct a quantitative analysis of bibliometric analysis. The results of our research show that there are 3 research fields: (i) platform-based new product development (ii) digital platform-based value co-creation (iii) digital platform-based business models. This paper compiled a list of the most prominent aspects in the manufacturing and digital platform literature, including leading countries, institutes, journals, authors, and articles. Finally, based on our analysis of the literature on manufacturing digital platforms, this paper summarized challenges and opportunities in these research fields.

Keywords: Manufacturing, Digital platform, Literature review, Business models

1. Introduction

Different industries are exploring how to carry out digital transformation to adapt to this digital age. As an essential tool and business model, digital platforms have become a rapidly developing research field in management and business disciplines [1]. According to Tiwana, Konsynski and Bush [2], digital platforms are an organizational form of technological architecture and governance mechanisms for managing autonomous complementors. Digital platform act as a conduit between all stakeholders and reflects their value by helping stakeholders to contact other stakeholders more easily and promoting the realization of business value [3]. The origins of the study of digital platforms are the study of manufacturing product platforms, such as automobiles [4]. Michael Cusumano is the key researcher in the research of digital platforms, which brings together platform theory and product platform [4]. Cusumano started from the study of automotive product platforms and expanded to the study of the whole platform theory and finally accelerated the development of digital platforms in manufacturing [4,5].

Platforms have recently garnered greater importance among global corporations due to their growing influence. An increasing number of manufacturing firms are adopting this method. Platform capabilities are viewed as a critical capability for enterprises [6]. As a result of the emergence of platforms, traditional business models are regularly put to the test. Apple's IOS and Google's SYMBIAN platforms, as instances of platform ecosystem development in the software industry, have built platforms that have gained tremendous success in recent years, thus asset-light tech firm driven by digital intermediary technologies and multiple rounds of venture capital financing that is the model of platform capitalism today [7]. Industrial organizations have recognized the critical nature of establishing digital platforms for digital transformation due to these changes in the sector. Meanwhile, a few emergent phenomena have hastened the pace of manufacturing firms' digital transformation, such as the Internet of Things (IoT), cloud computing, and big data, all of which have grown dramatically in recent years [8]. Manufacturing firms are increasingly capable of establishing digital platforms due to breakthroughs in these digital technologies. Manufacturing firms have been swept up in the tsunami of servitization business models [9]. Numerous advancements in digital transformation have impacted manufacturing companies. Like those owned by the Philips and Haier conglomerates, numerous established manufacturing firms have al-ready reaped the benefits of digital transformation through the usage of digital platforms [10,11]. Finally, the trend toward digital transformation mandates that manufacturing businesses shift their existing business models, leverage digital platforms to create platform ecosystems, and eventually convert to service and sustainability based on the vast data provided by digital platforms [12].

There has been a significant change in the literature available on digital platforms over the past 25 years. Recent literature reviews show that more attention is still paid to Internet enterprises, with little research on manufacturing [13]. As a result, the present research is neither systematic nor exhaustive enough to encompass all available literature on digital transformation in the manufacturing industry via digital platforms. This article presents a bibliometric analysis of manufacturing digital platforms (MDPs), covering 92 publications published between 1997 and 2022. We did a quantitative analysis using the HistCite and VOSviewer software programs. Then, we conducted the following research questions:

(RQ1) What are the most significant aspects of MDPs literature, such as the key countries, institutions, journals, authors, as well as the most influential and trending articles and topics?

(RQ2) What are the key research clusters in the MDPs literature?

(RQ3) What are the relevant research questions for further exploration of MDPs literature?

In this paper, two methodologies have been used: bibliometric analysis and content analysis [14-15]. Although the literature of review on digital platforms is still primarily based on traditional surveys of specific topics and issues [1,2,16]. Bibliometric analysis and content analysis are extensively used in the literature of review on Finance, management fields [6,15,17].

The remainder of this article is as follows: Section 2 details the study's methodology. Section 3 summarizes general and bibliometric findings. Section 4 discusses research results in thematic analysis. Section 5 discusses research agenda of MDPs literature. Section 6 discusses research contributions. The last section discusses research limitations.

2. Methodology

This article makes use of bibliometric analysis (quantitative) and content analysis (qualitative). Price [18] pioneered bibliometric analysis, which uses citations to determine the relationship between papers [19]. This technique is widely utilized in various fields, including the social sciences, and is especially prominent in business, management, and economics [20-21]. Qualitative content analysis is a multifaceted or flexible methodology used in the analysis of many social science studies and have been utilized by diverse fields of inquiry [20].

2.1 Sample selection process

The first step is the database selection to collect bibliometric data from academic papers. We selected the Web of Science Core Collection (WOS).

The second step is keyword selection. To ensure comprehensive data coverage, we used a two-step data collection [14]. First, the publication had to be counted as an article on the topic of MDPs. This includes a combination of the following search terms. (i) manufacturing (ii) digital platform or platform. To capture these articles, we used a combination of the terms mentioned in (i) and (ii). A combination of the terms mentioned in (i) and (ii): manufacturing and digital platform, manufacturing and platform. We choose articles in business, management, and economics to avoid articles in technical fields. Thus, we have an initial sample size of 470 papers, 62 in the first database and 398 in the second database.

The third step consisted of a detailed examination of the papers by reading the abstracts or the full papers (if applicable) to cross-check whether there were articles in the database that were suitable for our analysis. In the first dataset, 28 articles were left after manual censoring. In the second dataset, 64 articles were left. In this way, we obtained a sample of sample size of 92 articles (Year of publication from 1997 to January 2022).

2.2 Bibliometric analysis

For the bibliometric analysis, all the analysis was conducted using the HistCite and VOSviewer software. Both programs accept articles as input files and output a range of article-related information. The first software is HistCite. This paper identifies emerging themes from the relevant literature with

the help of HistCite. VOSviewer is a program that we have developed for constructing and viewing bibliometric maps. VOSviewer software employs distance-based mapping techniques to visualize objects and distinguish study genres by using diverse forms and colors based on citation information [15]. As a result of these investigations, we may better understand how genres are classified and how strong the relationships between them are [22]. Besides, we could do a map analysis and find keywords for each study stream using the VOSviewer application [15,22].

Next, we used content analysis to identify study clusters. First, we read 92 articles and documented the research content and research gaps. Second, we read the main articles of each cluster according to the result of bibliographic coupling analysis of VOSviewer. Finally, we summarize the main research clusters of MDPs, the research contents of each cluster and future research issues.

3. General & Bibliometric findings

3.1 General findings

3.1.1 Co-citation analysis of literature

We identified the major research streams in the literature in two phases. To begin, we conducted a co-citation study using the HistCite program, the results of which are depicted in Figure 1. The graphs depict how papers are cited cross-referenced in the literature. The year is indicated on the left in Figure 1. (y-axis). The circles represent the articles, the rows represent the citation links between the articles, and the size of the circle represents the number of citations. As a result, as seen in Figure 1, 20 articles become the most referenced. Number 7 article aim to more clearly understand the dynamics of platform renewal and derivative product generation and their consequences for long-term success [23]. As seen in the HistCite graph. This article provides a theoretical basis for the product platform for subsequent research. The eighth article examines how to use a platform approach to modular business models and is a key article on business models for manufacturing and digital platforms [24].

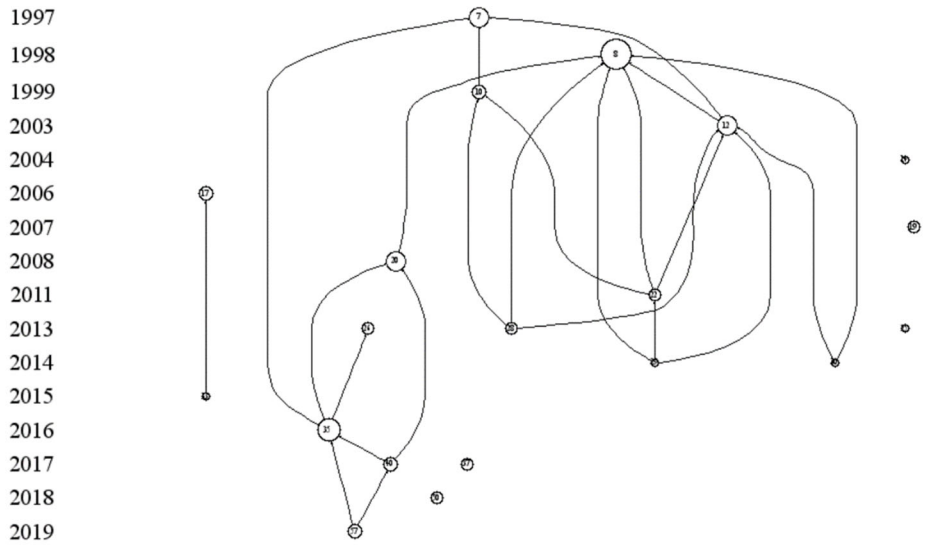

Fig. 1 Citation Mapping by HistCite software

3.1.2 The most influential aspects of the MDPs literature

The first wave of analysis found that the data sample includes 92 publications published in 65 journals by 272 authors affiliated with 181 institutions (Table1). The 92 papers received 66 local context citations (LCS) and 4374 global context citations (GCS). Then, we identified the most influential articles of MDPs by using HistCite software, including countries (Table2), institutions (Table3), journal (Table4), and article (Table5) scholars (Table6).

Table 1. Data sample

Search word	Search technique	No. of articles	Citations (ISI WOS)	Final sample (after exclusion)
Digital platform & Manufacturing	ISI WOS	62	1578	28
Platform & Manufacturing	ISI WOS	398	9661	64
Total number		460	11239	92

3.1.3 The most influential countries and institutions

We use the HistCite software to find which countries and institutions have a substantial impact on history. As part of the wave of manufacturing reform, various countries have proposed various manufacturing reform programs, including 'AMP2.0' in the United States, 'Industry 4.0' in Germany, and 'Made in China 2025' in China. As a result, it is vital to understand which countries and research institutions are doing and analyzing research on manufacturing digital platforms. We chose the top six countries and top five institutions based on the number of papers published by writers affiliated with these organizations. Table 2 and Table 3 offer a summary of the list's contents.

Table 2. The most influential countries

Rank	Country	Recs	TLCS	TGCS
1	USA	19	22	1965
2	China	18	4	533
3	UK	11	15	563
4	Sweden	10	11	345
5	Finland	8	19	487

Table 3. The most influential institutions

Institution	TLCS	TGCS
University of Pennsylvania	12	516
Aalto University	8	125
University of Cambridge	8	144
Luleå University of Technology	6	234
University of Vaasa	6	231

3.1.4 The most influential journals, articles and authors

We used the HistCite software to identify major journals, articles and authors in the field. The top five journals in the category are determined by the total number of articles records in each publication (Table 4). The top journals in the category being "Journal of manufacturing technology management" "International journal of technology management" and "Journal of product innovation management". 2020 journal impact factor (JIF) for these five journals are 7.547, 1.667, 6.987, 6.629, and 6.97 respectively, indicating that they are all very influential journals. Additionally, we identified the most influential articles using the HistCite software, based on the number of citations they got. Since the literature on digital platforms in manufacturing is still in its infancy, judgments are difficult to draw. The identification and debate of popular articles and ideas, the direction of prospective researchers, and the formulation of a research plan are all significant duties. We detected five significant papers. Table5 offers a summary of the list's contents. Researchers interested in collaborating on future study and articles can benefit from the directory of prestigious journals, articles and authors offered here [22].

Table 4. The most influential journals

Rank	Name of journal	Recs	LCS	GCS	2020 JIF
1	Journal of manufacturing technology management	6	177	1	7.547
2	International journal of technology management	5	60	1	1.667
3	Journal of product innovation management	5	235	11	6.987
4	International journal of operations&production management	3	45	3	6.629
5	Journal of operations management	3	348	0	6.97

Table 5. The most influential articles

Rank	Article	LCS	GCS
1	Robertson D; Ulrich K. Planning for product platforms. Sloan management review 1998, 39 (4), 19-+.	12	516
2	Eloranta V; Turunen T. Platforms in service-driven manufacturing: Leveraging complexity by connecting, sharing, and integrating. Industrial Marketing Management 2016, 55, 178-186.	7	82
3	Meyer MH; Tertzakian P; Utterback JM. Metrics for managing research and development in the context of the product family. Management Science 1997, 43 (1), 88-111.	5	159
4	Halman JIM; Hofer AP; van Vuuren W. Platform-driven development of product families: Linking theory with practice. Journal of product innovation management 2003, 20 (2), 149-162.	5	120
5	Pekkarinen S; Ulkuniemi P. Modularity in developing business services by platform approach. The International Journal of Logistics Management 2008, 19 (1), 84-103.	5	128

Table 6. The most influential authors

Rank	Author	Recs	LCS	GCS
1	Vinit Parida	4	6	234
2	Garza-Reyes, Jose Arturo	2	1	177
3	Meyer, Marc H.	2	5	165
4	Ville Eloranta	2	8	95
5	Turunen, Taija	2	8	95

3.2 Bibliometric findings

3.2.1 The clusters of digital platforms and manufacturing literature

The second phase was a thorough content study of these articles in order to find, explain, and validate their links. As a consequence of our review of the literature, we identified three primary study clusters. Additionally, as a check for robustness, we re-peated the bibliographic coupling analysis using the program VOSviewer. This appli-cation receives bibliographic data as input and produces a graph depicting the data flow in various colors. As seen in Figure 2, three distinct research clusters were constructed through VOSviewer. These articles are color-coded to indicate the three major study clusters in the literature: red and purple (platform-based new product development); blue and green (digital platform-based value co-creation), orange and cyan (digital plat-form-based business models). We used these keywords to conduct a literature search of the manufacturing digital platform for each cluster, with the purpose of studying the ex-pansion of these research topics in the manufacturing digital platform.

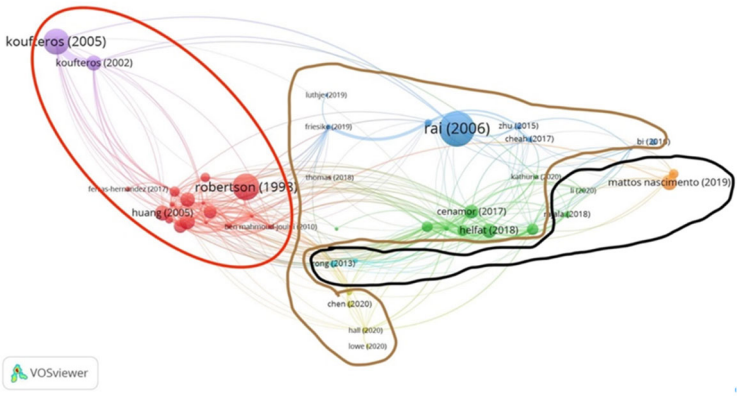

Figure 2. Bibliographic coupling analysis of 92 articles through VOSviewer software

We employed co-occurrence analysis [15] to identify and display the keywords in each cluster in figure 3. We found that purple and green represents platform-based new product development, red represent digital platform-based value co-creation, yellow and blue represents digital platform-based business models. We find that important keywords in platform-based new product development are technology, product platforms, and modularity. Key words in digital platform-based value co-creation are networks, servitization and digitalization. Key words in digital platform-based business models are innovation, manufacturing and environment.

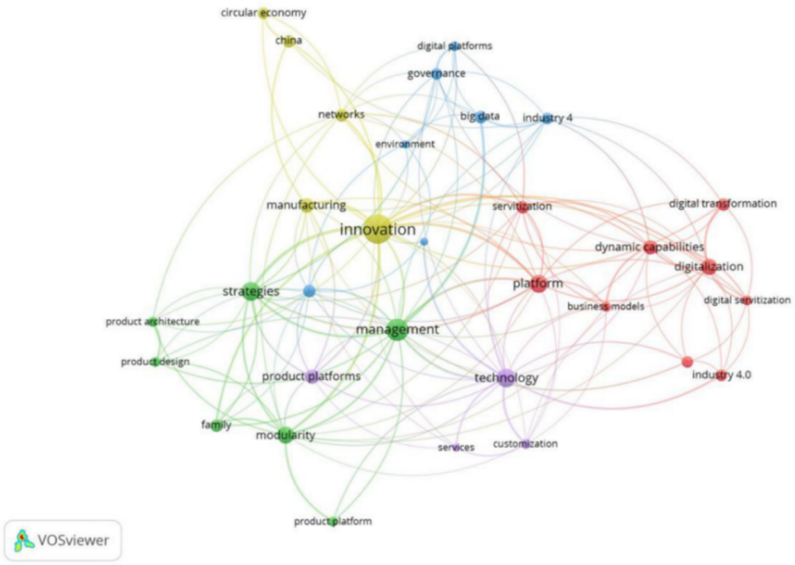

Figure 3. Co-occurrence analysis of all keywords through VOSviewer software

3.2.2 The evolutionary of digital platforms and manufacturing literature

Our study is primarily focused on the history, principles, and classifications of digital platforms in the manufacturing business. Since its beginnings in the car industry in the twentieth century, the term "platform" has been connected with manufacturing [4]. Thus, triggering manufacturing companies to use modular production to quickly generate other different products based on one product platform. The use of product platforms as a base structure. Enhance supply chain capabilities [23,27,31,32,33]. The move from analogue to digital platforms occurred in three stages. The original step was the product platform [23,25], which consisted of the twentieth-century automotive industry's use of an automotive chassis as a core product platform shared by several diverse models [4]. Because of Honda's success in utilizing automotive platforms and the expansion of the computer industry in the late twentieth century, academics began to expand their research on platforms outside the automotive sector to management and business strategy area, with the computer industry emerging as the primary focus of study [34,35,36]. The third stage of the procedure is the creation of a digital platform. Platforms will unavoidably demand digital characteristics as the twenty-first century's digital tsunami continues to sweep the globe. Uber and Amazon's digital platforms have revolutionized people's lives, while Apple's IOS and Google's Android operating systems, respectively, are developing digital platform ecosystems in the software business [2]. Manufacturing businesses are also anxious for digital transformation at the moment, and given the success of technology companies, it is critical for manufacturing firms to establish digital platforms for their operations [12].

3.2.3 Evolution of definitions related to MDPs

The digital platform of manufacturing industry is composed of two parts, one is the product platform, which is mainly applied to the internal production process of enterprises and generated through digital management of supply chain [23,27,30,32,33]. The other is a platform under the platform economy, an intermediary connecting markets from different user groups and relying on technology and information to facilitate the interaction of value creation [38,39,40]. At the same time, the combination of these two platforms can help manufacturing companies achieve efficient internal

and external communication. In our database of 92 articles, most of the articles use the software industry's definition of platform directly for definitions related to digital platforms in manufacturing, and another part uses the definition of platform economics under business models. Using HistCite software, we identified the most cited and most popular articles through a bibliometric analysis of each research stream, reviewed their content, and combined them to create a broader definition of digital platforms in manufacturing. As a result, our technical review led to the following broad definition of a manufacturing digital platform:

"A manufacturing digital platform is a production method, and business model applied by manufacturing companies that, internally, changes the production structure and coordinates production and departments, and externally, allows the exchange of value with consumers. Aim to improve business efficiency and increase consumer satisfaction."

Table 7. Definitions of digital platform and manufacturing

Definitions	Authors
Digital platform is a business model with enabled technology allowing producers and consumers to exchange value.	Mancha et al. (2018) Okano et al. (2021)
Digital Platform can be defined as external platforms based on software that consist of an extensible code base that provides the main functionality shared by the modules that interact with it and the interfaces through which they interoperate.	Tiwana et al. (2010) Ghazawneh and Henfridsson (2013)
Digital platform in manufacturing enables business process digitalization that links supply chain partners and supports information sharing in a timely manner.	Zhu et al. (2015)
Product platforms as a modular structure consisting of a set of physical components. Research on manufacturing service platforms decomposes the service architecture into several service modules.	Cenamor et al. (2017) Salvador et al. (2007) Voss et al. (2009)

4. Thematic analysiss

Two distinct theoretical views dominate digital platforms: one from economic theory and another from engineering design [45]. These distinct viewpoints define platforms as bilateral markets [46] or modular technological frameworks [47] respectively. Economic theory considers the manufacturing platform as a horizontal middleman that enables manufacturing enterprises to engage with a variety of stakeholders. The product design aspect employs vertical platform theory to increase the efficiency of manufacturing enterprises' product production [29]. Combining the classification results of HistCite and VOSviewer, we divided MDPs literature into three major clusters, namely (i) platform-based new product development (ii) digital platform-based value co-creation (iii) digital platform-based business models.

4.1 Platform-based new product development

To overcome the cost problems associated with increased product variety, various models have been designed and used to extend and enhance product lines. Platforms are one of them. This cluster can be divided into three sub-streams: principles and benefits, platform architecture, platform thinking.

Meyer and Lehnerd [23] define a platform as a collection of subsystems and interfaces that collectively form a generic structure upon which a variety of products can be built. According to Bratton and Benjamin [48], a stack is "a vertical sequence of modularity and interdependence" and "a platform that is also structured vertically through interoperability layers." Tiwana [49] defines a software platform as "a software-based extensible system that provides basic functionality that is shared by the applications it interacts with and the interfaces via which they communicate." All these platform definitions have in common the systematic reuse of components across products in a product family, enabling businesses to rapidly and efficiently develop subsequent products based on their product platform, with a strong platform providing leverage for each new derivative product to be developed at a low-cost relative to the primary product structure's development [23]. Thus, the

systematic development and utilization of economies of scope in innovation can be viewed as a key principle of platform-based new product development [45].

The platform architecture will be partitioned into stable core components and flexible periphery components in this perspective. Platforms are structurally stable by definition: innovation occurs on modules, inside a stable system architecture, and is facilitated by stable interfaces. Modular product architectures can help manufacturing companies innovate. This is because modularity improves management effectiveness by enabling organizations to integrate various modules into a product on a single production line, boosting manufacturing agility in three ways: operational flexibility, strategic flexibility, and structural flexibility [33,50]. Modularity, on the other hand, decreases the amount of knowledge required to build a module by reducing interdependence between modules to basic interconnection rules, allowing for specialization and division of inventive labor [51]. This enables both autonomous innovation inside modules and hybrid and matched innovation via inventive module reorganization [51]. For the commercial perspective of the modular structure, the approach to developing new products based on the platform concept is called platform product development and is one of the most important means to achieve mass customization strategies [52]. On the other hand, platform product development greatly controls and usually not only reduces costs but also reduces time-to-market to competitive levels [52].

Firms also need to utilize platform thinking. Platform thinking is the practice of discovering and capitalizing on shared logic and structure across an organization's operations and products in order to achieve leveraged growth and diversification. On the operational side, the company uses platform thinking to align internal and external players to positively influence product innovation and quality, and to influence profitability [37]. Platform thinking can be applied to the goods, brands, target markets, geographic markets, and business processes of a company [53]. Each of these dimensions serves as a platform for growth and variation. In short, these dimensions allow for a high degree of leveraged diversification inside a business [52,53].

4.2 Digital platform-based value co-creation

Digital platforms influence the way value is created at the front and back end of the business [28]. This cluster can be divided into two sub-streams: platform capability and servitization.

Digital platforms enable manufacturing companies to be more connected with their supply chain partners, thus enabling them to accomplish business activities together [54]. Companies with a high level of platform capability are able to improve the efficiency of transferring, integrating and processing the data collected from business partners and customers [38,55]. By facilitating a smooth flow of information within the focal enterprise and between supply chain partners, platform capabilities make it easy for manufacturing companies and their partners to identify bottlenecks in the supply chain and collaborate to find solutions to optimize business processes [28,38]. In business model from the perspective of the customer, the critical factor is the "network effects" that occur between the market's "two sides" [46,56,57]. The literature recognizes two distinct types of network effects: direct and indirect network effects. Direct network effects exist when the benefits of users' participation in a network are contingent on the number of other network users with whom they can interact [58], whereas indirect network effects exist when different sides of a network can benefit from the size and characteristics of the other side [57]. Adner and Kapoor [59] suggest that competitive advantage in a platform-mediated environment is highly dependent on platform enterprises' ability to promote value co-creation through their complementary networks and to capitalize on the resulting positive feedback dynamics [60]. Thus, strategic management research has concentrated on platform leadership [61,62] and strategic interactions with complementary players, while also examining strategic options for leveraging existing user bases [63,64].

Digital platforms assist manufacturing organizations to achieve a higher degree of servitization [29,65,66]. The term "servitization of manufacturing firms" refers to the gradual change of manufacturing companies' focus away from exclusively delivering industrial products and toward providing a combination of products and services with the purpose of better pleasing their customers

[65]. Coordination between the back-end (e.g., research and development departments) and the front-end (e.g., marketing and sales departments) is critical for establishing services [67]. Additionally, platforms enable the coordination of operations among various stakeholders in a way that maximizes value co-creation [68]. More precisely, platforms enhance interaction and enable businesses to assign responsibilities based on each participant's competitive advantage. These complex value offers must fulfil the rising diversity of consumer needs [69], but they face the danger of raising expenses and diminishing revenues, a phenomenon dubbed the 'service paradox' which the platform strategy can assist enterprises in resolving [29]. By utilizing the value of information and digital technologies, manufacturing businesses can successfully adopt enhanced services through a platform-centric architecture. Manufacturers integrate products, services, and information into a variety of enhanced service offerings, enabling them to offer a more diverse product portfolio at a competitive price. Platforms for digital product services are critical enablers of a variety of services. These platforms are intended to address a variety of product-related issues and to facilitate the adoption of new business models. The platform environment becomes critical during the servitization shift and is consequently difficult to acquire in the market. Manufacturing firms could establish their own platforms for digital product services, taking care to integrate business model innovation and platform development, including how to integrate their platforms with existing business operations [65].

4.3 Digital platform-based business models

Recent advancements in remote sensing, cloud computing, social media and mobile technologies, payment systems, and high-performance computing, particularly in the previous decade, have resulted in an exponential expansion of data, dubbed "big data" [70]. With big data, the digital connection between consumers and commodities captures not only their experience with the items, but also serves as a new economic resource [71]. The digital age is changing the manufacturing industry, disrupting the traditional business structures of industrial companies and forcing manufacturing companies to transform. This cluster can be divided into two sub-streams: sustainable business model and platform ecosystem.

A sustainable business model must be economically, environmentally, and socially sustainable: it must not only assist the company in significantly reducing its energy and material consumption, but also provide financial and social advantages while supplying the necessary products or services [11]. A sustainable business model balances the interests of all stakeholders and expressly recognizes the environment and society as critical stakeholders. Different value chains and business sectors can communicate and share information via a network of platforms. According to Li, Cao, Liu and Luo [11], it is the composition of the network connecting platforms that enables enterprises to transcend sectoral independence and establish coupling across dimensions. A network of complementary platforms spanning the organization will give information regarding processes, implementation, and performance, as well as enabling data synchronization. Since digital platforms provide robust digital support and complete visibility, they facilitate efficient internal and external communication and increase the coupling of dimensions. With this network, businesses can adopt a more intuitive approach to decision-making and resource allocation. Each dimension of a sustainable business model can be implemented as a digital platform, generating economic, environmental, and social advantages in the process [11,72].

Each actor constitutes the platform ecosystem. From the perspective of the digital platform, since it is necessary to understand what kind of new business models and business opportunities are possible in the Digital Ecosystem. The ecosystem idea highlights the interconnected nature of interorganizational networks, their cooperation and rivalry, their high degree of dependency, and their capacity to evolve in response to changes in the external environment [40]. According to platform ecosystem theories, platform's value is derived from the platform's complementarity with its complements [73]. Complementarity refers to the fact that when two or more objects are combined, their combined value exceeds the sum of their parts [74]. Complementarity works both ways in platform ecosystems: Without a platform core, supplemental items have minimal value; for example,

apps have no value without an operating system, and the value of a platform is contingent upon the availability of additional products that extend its capability. Scholars who study platform ecosystems frequently suggest that the value of a platform is contingent on the number of available or anticipated complements [10,68,75].

Table 8. Literature in each major cluster

Cluster	Key direction	Literature
Platform-based new product development	Principles and benefits of product development through platforms.	Meyer et al. (1997) Robertson and Ulrich (1998) Tatikonda MV (1999)
	Platform architecture and modularity	Huang et al. (2005) Pekkarinen and Ulkuniemi (2008)
	The significance of platform thinking	Koufteros XA et al. (2002) Huang et al. (2005)
Digital platform-based value co-creation	Platform capability as an enabler of value co-creation	Zhu et al. (2015) Rai et al. (2006) Bag S et al. (2021)
	Digital platforms assist manufacturing organizations to achieve a higher degree of servitization	Simonsson et al. (2020) Cenamor et al. (2017) Spring and Luis (2012)
Digital platform-based business models	Sustainable business model	Li X et al. (2020) Li k et al., (2020)
	Digital ecosystem	Hilbolling et al., (2021) Cheah S and Wang SH (2017) Rong K et al. (2013)

5. Research agenda of MDPs

For platform-based new product development, the existing model does not incorporate platform development and customization costs. This part of the cost should also be considered. In addition, existing platform models can incorporate additional metrics, for example, most studies of supply chains use supply chain cost as a performance metric to observe the impact of the platform. But other performance metrics, such as total supply chain profit, total supply chain cycle time, etc., are also necessary to be studied. Furthermore, there are many risks associated with developing an entirely new platform, and existing efforts do not clearly tell management when to create a new product platform. In calculating the cost of developing a product platform, the ideal data set would include manufacturing engineering, reprocessing, and marketing costs. But the reality of the lack of consistency between engineering, manufacturing and R&D systems is not uncommon in the industry, making it difficult for developers to collect this data in their companies. How to address this phenomenon is also a future research agenda. Finally, the available empirical data on the development of modularization are from large companies, so further research is needed to clarify the prerequisites and methods for developing modularization in small and medium-sized service companies; to find out what the challenges of using modularization in small companies are and how these challenges differ from those of large companies. As companies mature in their ability to combine servitization and digitization, and as academic research on digital servitization increases in the coming years, we are calling for more research on how manufacturing companies can leverage platforms to enable digital servitization. The current study on the realization of the platform as a service adopts an internal perspective.

Future research should examine how manufacturing companies can develop digital platform development processes that cut across traditional product development logic. Future research could expand the perspective of the platform approach to combine producer and consumer perspectives. Such an analysis includes network partners and customers. For example, insights into external perspectives, especially customers, would provide a more comprehensive understanding of how the platform approach influences the service process. At the same time, the difficulty and cost of building the platform may lead companies to consider outsourcing the platform development. Future research could explore which parts of the platform companies should outsource and how to manage them. For example, enterprises could outsource non-core operations and protect data security through legal mechanisms that mitigate the risk of data loss, illegal use, tampering, or leakage.

How manufacturing companies can achieve the goal of service and sustainability through the digital platform-based business model is the key research direction in the future. Besides, future research could examine in more detail the interdependencies of the elements in a platform-based business model interdependencies, particularly how the processes of the business model-value discovery, creation, and realization-interact. The balance and transfer mechanisms of economic, environmental, and social benefits within manufacturing firms still need to be studied. For example, whether manufacturing firms that adopt digital platform technologies have higher performance in terms of social, environmental, and economic indicators.

Table 9. Future research questions

Research Streams	Future Research Questions
Platform-based new product development	How to improve the existing platform development model?
	How to address the risks faced in developing a manufacturing product platform?
	How do small and medium-sized manufacturing companies develop their product platforms?
Digital platform-based value co-creation	How can manufacturing companies develop digital platform development processes that cut across traditional product development logic?
	A consumer perspective on how platforms can be made serviceable.
	Should companies outsource the platform development work?
Digital platform-based business models	How to achieve service and sustainability through the digital platform-based business model?
	What is the interdependence of the elements in the business model of the platform?
	Do manufacturing companies that adopt digital platform technologies have higher performance in terms of social, environmental and economic indicators?

6. Conclusion

We expand the existing literature on digital platform research. In business economic and management area, this is the first quantitative survey of the literature on manufacturing digital platforms. This study contributes to the field of digital manufacturing platforms research in a variety of ways. We begin by discussing the origins and categories of digital platforms in manufacturing and use this information to create a broader definition of digital platforms in manufacturing. Second, we identify the key countries, institutions, journals, authors, and influential papers and themes in the field of digital manufacturing platforms for research. Thirdly, we identify three important clusters of the literature. Fourth, we discuss the development of the literature in each cluster and suggest future research agenda.

Our research review on MDPs highlights a rich body of literature that contributes to our understanding of the benefits and challenges associated with digital platforms for manufacturing companies on multiple levels. We found the main clusters： (i) platform-based new product development (ii) digital platform-based value co-creation (iii) digital platform-based business models.

We believe that the three research clusters we propose can help us better understand the strategic implications of MDPs and the ways in which manufacturing companies can use digital platforms as a digital technology. In addition to these, future research may use our framework as a guide to amplify and investigate the specific relationships of our inductive framework.

Finally, our study has practical guidance for manufacturing enterprises seeking digital transformation. We provide theoretical guidance on how to develop digital platform for manufacturing enterprises. Enterprises can adapt their development of digital platforms based on our research.

7. Limitations

The study's potential limitations stem from the bibliometric analysis. Because the analysis concentrated on widely referenced articles, it is possible that the software missed some high-quality research articles that were not cited. We covered a large range of literature up to January 2022, but recent articles need time to be cited. Therefore, we recommend applying this technique again several years from now. Additionally, we analyzed bibliometric citations using a single database (ISI WOS). We advocate conducting bibliometric citation analysis on MDPs literature that also including data from other databases (e.g., Google Scholar).

References

[1] Vial, G. Understanding digital transformation: A review and a research agenda. The Journal of Strategic Information Systems 2019, 28(2), pp.118-144.

[2] Tiwana, A.; Konsynski, B.; Bush, A. Research Commentary—Platform Evolution: Coevolution of Platform Architecture, Governance, and Environmental Dynamics. Information Systems Research 2010, 21(4), pp.675-687.

[3] Bonollo, N.; Poopuu, P. The impact of digital platforms on roles and responsibilities in value creation among stakeholders of an ecosystem 2019.

[4] Steinberg, M. From Automobile Capitalism to Platform Capitalism: Toyotism as a prehistory of digital platforms. Organization Studies 2021, p.017084062110306.

[5] Cusumano; Michael A.; Gawer; Annabelle; Yoffie; David B. The business of platforms: Strategy in the age of digital competition, innovation, and power. New York: HarperCollins, 2019; pp. 1-309.

[6] Agostini, L.; Nosella, A. Industry 4.0 and business models: a bibliometric literature review. Business Process Management Journal 2021, 27(5), pp.1633-1655.

[7] Srnicek; Nick. Platform capitalism. John Wiley & Sons, 2017.

[8] Okano, M.T.; Antunes, S.N.; Fernandes, M.E. Digital transformation in the manufacturing industry under the optics of digital platforms and ecosystems[J]. Independent Journal of Management & Production 2021, 12(4), pp.1139-1159.

[9] Paschou, T.; Rapaccini, M.; Adrodegari, F.; Saccani, N. Digital servitization in manufacturing: a systematic literature review and research agenda, Industrial Marketing Management 2020, Vol. 89, pp. 278-292.

[10] Hilbolling, S.; Berends, H.; Deken, F.; Tuertscher, P. Sustaining Complement Quality for Digital Product Platforms: A Case Study of the Philips Hue Ecosystem. Journal of Product Innovation Management 2020, 38(1), pp.21-48.

[11] Li, X.; Cao, J.; Liu, Z.; Luo, X. Sustainable Business Model Based on Digital Twin Platform Network: The Inspiration from Haier's Case Study in China. Sustainability 2020, 12(3), p.936.

[12] Favoretto, C.; Mendes, G.; Filho, M.; Gouvea de Oliveira, M.; Ganga, G. Digital transformation of business model in manufacturing companies: challenges and research agenda. Journal of Business & Industrial Marketing 2021, ahead-of-print(ahead-of-print).

[13] Chen, L.; Tong, T.; Tang, S.; Han, N. Governance and Design of Digital Platforms: A Review and Future Research Directions on a Meta-Organization. Journal of Management 2021, 48(1), pp.147-184.

[14] Alon, I.; Anderson, J.; Munim, Z. H.; Ho, A. A review of the internationalization of Chinese enterprises. Asia Pacific Journal of Management 2018, 35(3), 573–605.

[15] Bahoo, S.; Alon, I.; Paltrinieri, A.; Sovereign wealth funds: Past, present and future. International Review of Financial Analysis 2020, 67, p.101418.

[16] Liang, Q.; Gou, J.; Li, W.; Huang, L. Exploring the Barriers and Mitigation Strategies in Digital Business Ecosystem Development: A Case Study from Engineering Material Supply Service Provider. Boosting Collaborative Networks 4.0 2020, pp.19-30.

[17] Annarelli, A.; Battistella, C.; Nonino, F.; Parida, V.; Pessot, E. Literature review on digitalization capabilities: Co-citation analysis of antecedents, conceptualization and consequences. Technological Forecasting and Social Change 2021, 166, p.120635.

[18] Price, D. de S. Networks of scientific papers cited by me. Science 1965, 149(March).

[19] Ahmed, F.; Bahoo, S.; Ayub, A. Accountability, governance and structure of non-profit organizations: Evidence from Ghana, South Africa, and Zimbabwe. New Horizons 2019, 13(2), 19–36.

[20] Tao, Y.; He, J.; Wang, Y.; Ke, H. Strategic Leadership: A Bibliometric Analysis on Current Status and Emerging Trends. International Journal of Organizational Leadership 2021, 10(4), pp.439-458.

[21] Ahmad, S.; Bajwa, I. The role of social entrepreneurship in socio-economic development: a meta-analysis of the nascent field. Journal of Entrepreneurship in Emerging Economies 2021.

[22] Eck, Nees Jan Van; Ludo Waltman. Visualizing bibliometric networks. Measuring scholarly impact 2014, pp.285-320.

[23] Meyer MH; Tertzakian P; Utterback JM. Metrics for managing research and development in the context of the product family. Management Science 1997, 43 (1), pp.88-111.

[24] Pekkarinen, S; Ulkuniemi, P. Modularity in developing business services by platform approach. The International Journal of Logistics Management 2008, 19 (1), 84-103.

[25] Robertson, D; Ulrich K. Planning for product platforms. Sloan management review 1998, 39 (4), 19-+.

[26] Eloranta, V; Turunen T. Platforms in service-driven manufacturing: Leveraging complexity by connecting, sharing, and integrating. Industrial Marketing Management 2016, 55, 178-186.

[27] Halman, JIM; Hofer AP; van Vuuren W. Platform-driven development of product families: Linking theory with practice. Journal of product innovation management 2003, 20 (2), 149-162.

[28] Rai, A; Patnayakuni R; Seth N. Firm performance impacts of digitally enabled supply chain integration capabilities. MIS quarterly 2006, 30 (2), 225-246.

[29] Cenamor, J; Sjodin, DR; Parida, V. Adopting a platform approach in servitization: Leveraging the value of digitalization. International Journal of Production Economics 2017, 192, 54-65.

[30] Kohtamaki, M; Parida, V; Oghazi, P; Gebauer, H; Baines T. Digital servitization business models in ecosystems: A theory of the firm. Journal of Business Research 2019, 104, 380-392.

[31] Tatikonda MV. An empirical study of platform and derivative product development projects. Journal of Product Innovation Management 1999, 16 (1), 3-26.

[32] Jiao J; Ma Q; Tseng M M. Towards high value-added products and services: mass customization and beyond[J]. Technovation 2003, 23(10), 809-821.

[33] Watanabe C; Ane B K. Constructing a virtuous cycle of manufacturing agility: concurrent roles of modularity in improving agility and reducing lead time. Technovation 2004, 24(7), 573-583.

[34] Wheelwright S C; Clark K B. Creating project plans to focus product development. Harvard Business School Pub 1992.

[35] Cusumano, Michael A.; Richard W. Selby. Microsoft secrets: how the world's most powerful software company creates technology, shapes markets, and manages people. Simon and Schuster, 1998.

[36] Cusumano, Michael A. Staying power: Six enduring principles for managing strategy and innovation in an uncertain world (lessons from Microsoft, Apple, Intel, Google, Toyota and more). Oxford University Press, 2010.

[37] Koufteros; Xenophon A.; Mark A.; Vonderembse; aWilliam J. Doll. Integrated product development practices and competitive capabilities: the effects of uncertainty, equivocality, and platform strategy. Journal of Operations Management 2002, 20.4, 331-355.

[38] Zhu, Z.; Zhao, J., Tang, X.; Zhang, Y. Leveraging e-business process for business value: A layered structure perspective. Information & Management 2015, 52(6), 679-691.

[39] Helfat, C. E.; Raubitschek, R. S. Dynamic and integrative capabilities for profiting from innovation in digital platform-based ecosystems. Research policy 2018, 47(8), 1391-1399.

[40] Han Y. A tripartite evolutionary game analysis of enterprises' behaviour in the platform ecosystem. Discrete Dynamics in Nature and Society 2020.

[41] Mancha R; Gordon S; Iyer B. Figayou pursues a platform strategy: A case study of digital platform entrepreneurship. Journal Of Information Technology Case And Application Research 2018, 20(2), 55-70.

[42] Ghazawneh A; Henfridsson O. Balancing platform control and external contribution in third-party development: the boundary resources model. Information systems journal 2013, 23(2), 173-192.

[43] Salvador F. Toward a product system modularity construct: literature review and reconceptualization. IEEE Transactions on engineering management 2007, 54(2), 219-240.

[44] Voss Christopher A.; Juliana Hsuan. Service architecture and modularity. Decision Sciences 2009, 40.3, 541-569.

[45] Gawer A. Bridging differing perspectives on technological platforms: Toward an integrative framework. Research policy 2014, 43(7), 1239-1249.

[46] Rochet J C.; Tirole J. Platform competition in two-sided markets. Journal of the european economic association 2003, 1(4) 990-1029.

[47] Baldwin C Y; Woodard C J. The architecture of platforms: A unified view. Platforms, markets and innovation 2009, 32, 19-44.

[48] Bratton, Benjamin H. The stack: On software and sovereignty. MIT press, 2016.

[49] Tiwana, Amrit. Platform ecosystems: Aligning architecture, governance, and strategy. Newnes, 2013.

[50] Langlois RN. Modularity in technology and organization. Journal of Economic Behavior and Organization 2002, 49, 19–37.

[51] Garud, R.; A. Kumaraswamy. Technological and organizational designs for realizing economies of substitution. Strategic Management Journal 1996, 16, 93–109.

[52] Huang GQ; Zhang XY; Liang L. Towards integrated optimal configuration of platform products, manufacturing processes, and supply chains. Journal of operations management 2005. 23 (3-4), 267- 290.

[53] Sawhney, M.S. Leveraged high-variety strategies: from portfolio thinking to platform thinking. Journal of the Academy of Marketing Science 1998, 26(1), 54-61.

[54] Saraf N; Langdon C S; Gosain S. IS application capabilities and relational value in interfirm partnerships. Information systems research 2007, 18(3), 320-339.

[55] Barua A; Konana P; Whinston A B, et al. An empirical investigation of net-enabled business value. MIS quarterly 2004: 585-620.

[56] Evans DS. Some empirical aspects of multi-sided platform industries. Review of Network Economics 2003, 2, 191–209.

[57] Armstrong M. Competition in two-sided markets. RAND Journal of Economics 2006, 37, 668–691.

[58] Parker GG; Van Alstyne MW. Two-sided network effects: a theory of information product design. Management Science 2005, 51, 1494–1504.

[59] Adner R; Kapoor R. Value creation in innovation ecosystems: how the structure of technological interdependence affects firm performance in new technology generations. Strategic Management Journal 2010, 31, 306–333.

[60] Katz ML.; Shapiro C. Technology adoption in the presence of network externalities. Journal of Political Economy 1986, 94, 822–841.

[61] Gawer A; Cusumano MA. Platform Leadership: How Intel, Microsoft and Cisco Drive Industry Innovation. Harvard Business School Press: Boston, MA 2002.

[62] Gawer A; Henderson R. Platform owner entry and innovation in complementary markets: evidence from Intel. Journal of Economics and Management Strategy 2007, 16, 1–34.

[63] Cennamo C; Santalo S. Platform competition: strategic trade-offs in platform markets. Strategic Management Journal 2013, 34, 1331–1350.

[64] Kapoor R; Lee JM. Coordinating and competing in ecosystems: how organizational forms shape new technology investments. Strategic Management Journal 2013, 34, 274–296.

[65] Simonsson J; Magnusson M; Johanson A. Organizing the Development of Digital Product-Service Platforms. Technology Innovation Management Review 2020, 10 (3), 36-47.

[66] Sun, X.; Zhang, Q. How can dynamic capabilities make sense in avoiding value co-creation traps? Management Decision 2021, 60(3), pp.735-757.

[67] Silvestro R; Lustrato P. Exploring the "mid office" concept as an enabler of mass customization in services. International Journal of Operations & Production Management 2015.

[68] Thomas L D W; Autio E; Gann D M. Architectural leverage: Putting platforms in context. Academy of management perspectives 2014, 28(2), 198-219.

[69] Baines T.; Lightfoot H. Made to serve: How manufacturers can compete through servitization and product service system. John Wiley & Sons, 2013.

[70] Cheah S; Wang S. Big data-driven business model innovation by traditional industries in the Chinese economy[J]. Journal of Chinese Economic and Foreign Trade Studies 2017.

[71] Ng, I.C. New business and economic models in the connected digital economy. Journal of Revenue and Pricing Management 2014, Vol. 13 No. 2, pp. 149-155.

[72] Li, K.; Kim, D.; Lang, K.; Kauffman, R.; Naldi, M. How should we understand the digital economy in Asia? Critical assessment and research agenda. Electronic Commerce Research and Applications 2020, 44, p.101004.

[73] Jacobides, M. G.; C. Cennamo; A. Gawer. Towards a theory of ecosystems. Strategic Management Journal 2018, 39 (8), 2255–76.

[74] Baldwin, C. Y. Design rules (Volume 2): How technology shapes organizations. Chapter 5: Complementarity. Harvard Business School Working Paper 19-036, 2018.

[75] Clements, M. T.; H. Ohashi. Indirect network effects and the product cycle: Video games in the US, 1994–2002. The Journal of Industrial Economics 2005, 53 (4), 515–42.

[76] Spring M.; Araujo L. Beyond the service factory: Service innovation in manufacturing supply networks. Industrial marketing management 2013, 42(1), 59-70.

[77] Bag, S.; Telukdarie, A.; Pretorius, J. C.; Gupta, S. Industry 4.0 and supply chain sustainability: framework and future research directions. Benchmarking: An International Journal 2018.

[78] Rong, K.; Lin, Y.; Shi, Y.; Yu, J. Linking business ecosystem lifecycle with platform strategy: a triple view of technology, application and organisation. International journal of technology management 2013, 62(1), 75-94.