Platform Operations in the Industry 4.0 Era: Recent Advances and the 3As Framework

Tana Siqin, Tsan-Ming Choi, Sai-Ho Chung, and Xin Wen

***Abstract*—In the Industry 4.0 era, implementing advanced technologies to enhance platform operations is crucial. Motivated by the importance of platforms and the wide implementation of Industry 4.0-related advanced technologies, we conduct this study on platform operations. Specifically, the platforms discussed herein are classified into (pure) product selling platforms and service platforms. We identify the platform-related operational issues in four categories: 1) the use of information, 2) operating/manufacturing processes, 3) decision support, and 4) consumer behavior and marketing. Based on the examined real-world practices and reviewed prior studies, we propose the novel "3As" framework to indicate how platforms should "adopt" advanced technologies to "address" operational issues to "achieve" outcomes. In addition, the "3As" framework uncovers possible platform innovations with three extended developments. Finally, we present a future agenda for further studies on the use of advanced technologies in platform operations. This article contributes to the operations and engineering management literature by generating insights regarding the implementation of advanced technologies in platform operations in the Industry 4.0 era.**

***Index Terms*—The "3As framework", advanced technologies, Industry 4.0 era, platform operations.**

I. Introduction

A. Background

WITH the advancement of technologies, modern business operations have entered the digital era [10], [45], and the sharing economy has been established. Toward facilitating the connection and collaboration among various parties in the sharing economy, platforms of all kinds (from social media, e.g., WhatsApp [86], to giant e-commerce platforms, e.g., Amazon) are now very popular in practice. In fact, as reported,[1] six of the ten most valuable brands worldwide have adopted the platform-based business mode in 2021, including Apple, Amazon.com, and Google. This shows the importance of platforms for the modern economy. Platform operations have thus attracted extensive research interests from academia [11].

Platforms can be basically categorized into (pure) product selling (PS) platforms and service platforms according to the functions they serve.[2] Specifically, PS platforms, such as Amazon.com, function as a marketplace where products can be exchanged among several parties, including brands and consumers. Conversely, service platforms focus on providing services for users, rather than selling products. Typical service platforms include social media platforms (e.g., Facebook), resource sharing platforms (e.g., WeWork), and decision support (DCS) [95] platforms (e.g., SAP). As pointed out by Gawer [32] and Rochet and Tirole [65], the platform side is a crucial factor that affects the tactical strategies of platforms and operational performances. Therefore, examining the impacts of the sides involved in platform operations becomes crucial. From this perspective, platforms can be further divided into one-, two-, and *n*-sided platforms. One-sided platforms are those that serve users themselves. For instance, SAP provides powerful DCS in enterprise resource planning for consumers through its platform. Contrariwise, two-sided platforms act as the bridge to link two groups of users and create value by facilitating the interaction between them [38]. *N*-sided platforms, however, involve more than two parties. A typical example is the social media platform, where diverse groups (e.g., users, advertisers, and content providers) interact with each other. In fact, most PS platforms are two-sided [37]. For example, brands can display their products on Amazon.com, such that consumers can select and buy items on this two-sided platform. In the literature, it is common to see one-sided service (OS) platforms (e.g., SAP), two-sided service (TS) platforms (e.g., PayPal), as well as *n*-sided service (NS) platforms (e.g., Facebook) [37].

In recent years, the business world has been stepping into Industry 4.0,[3] which is characterized by the fast development of various disruptive technologies (e.g., blockchain [54], [69], [74], [87], [92], big data [5], [77], [80], and artificial intelligence). These disruptive technologies have reshaped the entire business environment. As revealed from the recent literature (e.g., [16] and [58]), additive manufacturing (AM), the Internet of Things (IoT), blockchain technology (BT), and big data are the major well-adopted advanced technologies emerging in the Industry

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[1]https://brandirectory.com/rankings/global/ accessed on September 20, 2021.

[2]In the literature, there are other categorization paradigms for platforms. We will introduce them in Section II. Abbreviations used in this article are provided in Table X in Appendix B.

[3]This terminology was proposed by the German government's high-tech strategy project that aims to impel manufacturing in computerization. [Online]. Available: https://ati.ec.europa.eu/reports/policy-briefs/Germany-industry-40 accessed on September 20, 2021.

TABLE I
WELL-ADOPTED ADVANCED TECHNOLOGIES IN THE INDUSTRY 4.0 ERA

Areas	**Technologies**	**Definitions**	**Applications**
Productions	Additive manufacturing (AM)	AM (or called 3D printing [36] is an industrial production process controlled by computers to produce dimensional objects by using depositing materials.	AM is currently being used in various industries, such as aerospace and manufacturing. As an emerging technology, AM is known for its ability to create sophisticated and customized products with fast speed [22].
Connections	Internet of Things (IoT)	IoT represents a network of physical objects which are connected by sensors, software, and other technologies to collect and exchange data.	IoT can help with rapid manufacturing by facilitating quick response to dynamic market changes due to the integration of objects [34].
Data records	Blockchain technology (BT)	BT is a form of distributed ledger that consists of blocks in an information chain.	BT has been widely used in finance. In operations management, BT is viewed as an approach to improve the transparency, security, and efficiency of transactions [4].
Data analysis	Big data	Big data refers to the data set with the characteristics like large volume and high variety, which can be analyzed to generate insightful implications [67].	Big data has been widely applied in various areas for the purposes like forecasting and classification[4] [17].

4.0 era (hereafter advanced technologies) that derive significant impacts on operations management (OM). The definitions and classical applications of these advanced technologies are summarized in Table I. As can be seen from Table I, the economy has witnessed the wide application of these advanced technologies in various industries (e.g., manufacturing and data analytics) with diverse functions (e.g., systems connection and forecasting). Platform operations are typically technology-based. The application of technologies is popular, and it attracts much attention. For instance, platform-oriented enterprises, such as Amazon, SAP, PayPal, and Facebook, have widely implemented the aforementioned technologies in their operations.

B. Research Questions and Contribution Statement

Prior review and conceptual studies have focused on the operations of platforms (e.g., [11], [26], and [32]). Specifically, Facin *et al.* [26] discuss the evolution of platforms by systematically reviewing the related literature. The authors report that the concept of platforms has gradually changed from product development to platform-based business management. Based on Facin *et al.* [26], Chen *et al.* [11] propose the research opportunities associated with online platforms in the OM domain from the viewpoint of business modes (e.g., resource sharing, crowdsourcing, and crowdfunding). Moreover, Gawer [32] comprehensively explores the optimal platform operational strategies, while considering the role of platform boundaries and identifies the important factors that influence decision-making. Several prior works have conceptualized the application of advanced technologies in the Industry 4.0 era. For instance, Zhong *et al.* [94] summarize the latest development of intelligent manufacturing supported by advanced technologies and propose a future research agenda. Dilberoglu *et al.* [22] investigate the role of AM in various industries. For the implementation of Industry 4.0 technologies in sustainable manufacturing and the related supply chain operations, Felsberger and Reiner [27] conduct a multimethod study with a literature review and interviews to comprehensively investigate the current research and practices. Albeit Industry 4.0 and its implementations are burning topics in OM and relevant domains, how the advanced technologies of Industry 4.0 can improve the operations of various platforms remains underexplored. Overall, platform operations and the deployment of advanced Industry 4.0 technologies are popular research topics. However, how the advanced technologies can help improve platform operations as well as the related challenges is underexplored. Thus, we develop this study to bridge this important research gap. Table II provides the comparisons between this study and other related studies.

Motivated by the importance of platform operations in the Industry 4.0 era and the underexplored impacts of advanced technologies on the related OM challenges, we carry out this study with the aim of answering the following questions.

1) What are the major advanced technologies applied to support platform operations in Industry 4.0 as revealed from the literature and the industry?
2) What are the main operational issues arising from the implementations of these advanced technologies?
3) How do different types of platforms improve their operations with these advanced technologies to benefit the economy, the society, and the entire ecosystem?
4) Can a framework to guide the implementations of these advanced technologies toward enhancing platform operations be conceptualized?

[4]It is noticed that big data includes terminologies that are related to its analytics, such as statistics, data mining, and artificial intelligence.

TABLE II
COMPARISONS BETWEEN THIS STUDY AND OTHER RELATED STUDIES

Topics	Previous literature	Problem studied	Differences between our current study
Platform related	[26]	The evolution of platforms	We pay attention to study the platform operations in Industry 4.0, especially for the implementation of advanced technologies in different types of platforms
	[11]	Business mode of platforms and research opportunities	
	[32]	The boundaries of platform	
Advanced technologies related	[94]	The implementation of advanced technologies in intelligent manufacturing	We comprehensively study how advanced technologies can be implemented in improving the platform operations
	[22]	The implementation of additive manufacturing	
	[27]	The implementation of Industry 4.0 technologies in sustainable manufacturing	

5) Are there any underinvestigated problems or topics that deserve further exploration?

Addressing the aforementioned questions can offer valuable insights that would contribute to the engineering management literature and enhance practices. The contribution of this study is threefold. First, we uncover the state of the art in research progress and industrial practices regarding the implementation of advanced technologies on platform operations. Moreover, different from the prior related studies, the implications can be revealed more clearly from the perspectives of both platform sides and functional types. Second, combining the findings from the literature review and examined real practices, we propose a novel framework termed the "3As" framework that can facilitate the development of platforms in the Industry 4.0 era, including transformations and collaborations for advanced technology implementations. Moreover, the proposed framework can provide regulatory guidance to enhance platform operations, which contributes to the further development of the platform economy. Third, a future research agenda is proposed to help identify further exploration directions and expand the domain to attract more attention. Overall, this study not only advances the understanding of platform operations in the Industry 4.0 era but also lays a solid foundation for future research in the domain.

II. METHODOLOGY AND RESEARCH FLOW

This article is composed of four major parts, including the literature review (Sections III and IV), real case studies (Section V), summary for the implementation of advanced technologies (Section VI), development of the "3As" framework (Section VII), and the proposal for future agenda (Section VIII). In the following, we introduce the research methodology as well as the research logic of this study.

First, following the concept proposed by Croom *et al.* [19], we conduct a critical literature review to identify the implementations of advanced technologies in improving platform operations. The critical literature review starts with keyword searching and ends with stepwise classification. Initially, we search for keywords of "platform" with those relevant to advanced technologies (e.g., Industry 4.0, AM, IoT, etc.) in Web of Science. Note that we focus on mainstream OM and information systems journal to narrow down the research scope (the list of the selected journals is provided in Table IX in Appendix B[5]). Ninety papers are identified in this step. Thereafter, we filter those papers by manually checking whether the papers examine problems about platform operations with the use of advanced technologies; 43 papers remain after filtering. Moreover, we supplement four important papers that are suggested by the reviewers and other experts in the field (P.S.: Figure O1 in Online Appendix A shows the trend of publications over the years). Finally, we classify the selected papers from two aspects (e.g., function and sides) as discussed in Section I. The paper selection steps are described in Fig. 1.

Notably, the existing review studies have applied a variety of paper classification schemes, including 1) according to the type of products (e.g., service, capital, product, etc.) transacted among sides, 2) according to the business models of platforms (e.g., resource sharing, crowdsourcing, etc.), and 3) according to the operation models of platforms (e.g., transaction platforms and innovation platforms) [11], [26], [32]. Our classification scheme is in fact similar to 1), as PS platforms entail the transaction of products, while service platforms facilitate the transaction of services. Furthermore, following the existing literature [38], [84], the studies in each category are further classified according to the number of platform sides involved; thus, the crucial impact of side on platform operations could be evaluated. Note that, herein, instead of investigating the transformation of platform sides [7], we intentionally explore the effect of advanced technologies in improving platform operations for different-sided platforms separately. Through preliminary studies, it is identified that the research focusing on PS platforms is rather limited compared with that on service platforms. Additionally, the majority of the PS platform literature does not specify the sides involved. Therefore, in this article, we determine the sides of the PS platforms considered in the selected literature based on the definition of the platform side and the given information in the literature. Specifically, almost all the PS platforms examined in the selected literature are two-sided. However, for the papers on service platforms, we can apparently classify them into OS, TS, and NS platforms. According to our applied paper classification scheme, we are able to identify the main categories and issues of the operations for each platform type studied in the existing

[5]We also incorporate important journals from other relevant fields (e.g., marketing) to guarantee that the selected papers are comprehensive and complete.

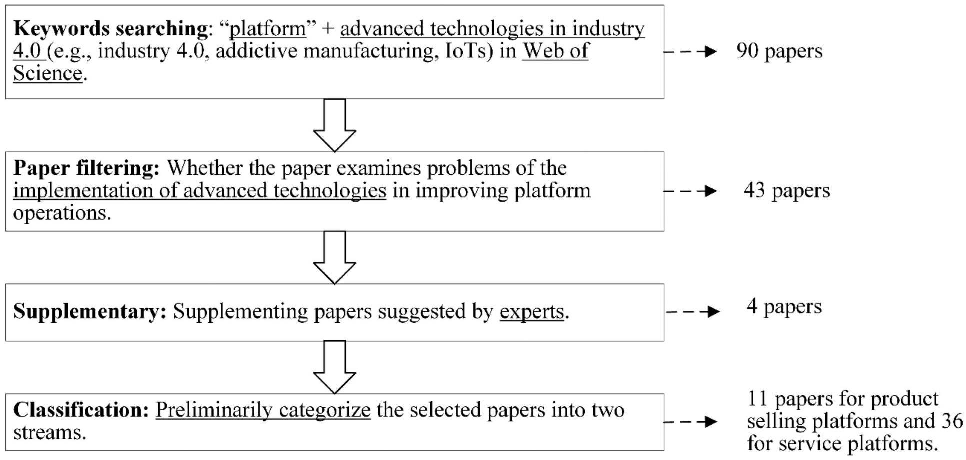

Fig. 1. Paper selection steps for the literature review.

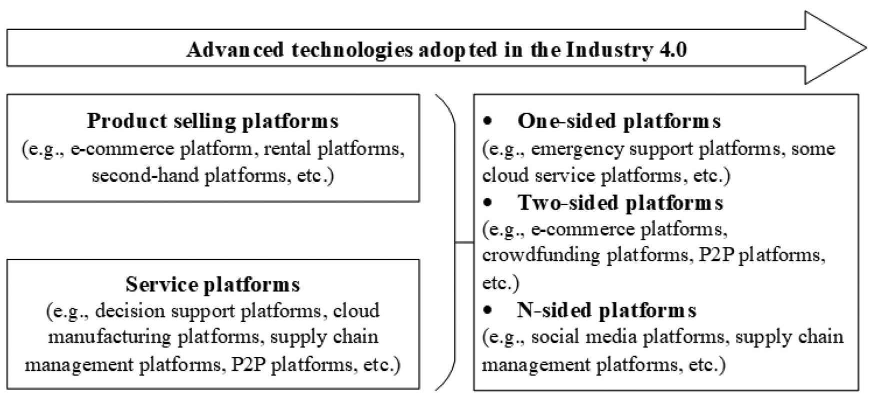

Fig. 2. Classifications of platforms.

literature. Moreover, we are also inclined to examine how the advanced technologies could help to improve the operations of each type of platform in Industry 4.0. The structure of the literature reviewed in this article is depicted in Fig. 2.

Second, based on findings revealed from the literature review, we further carry out four real case studies for the four platform types examined in this work. In reality, the implementation of advanced technologies in platforms has newly emerged with the development of Industry 4.0. Accordingly, it is of great significance to examine the latest practice in the industry. Following Siggelkow [72] and Yin [89], we carry out the "single case study" method aimed at an in-depth exploration into the implementation of different advanced technologies for each type of platform. Specifically, four enterprises that have applied advanced technologies in their platform operations are selected to represent the PS, OS, TS, and NS platforms, respectively. They are Amazon, SAP, PayPal, and Facebook. Note that even though each of the selected enterprises may undertake different business operations, platforms are one of the main businesses of the enterprise. Therefore, we focus on the implementation of technologies in platform operations when conducting case studies. For example, Amazon has developed itself as a multi-business company that involves in several activities, including cloud computing and local services. However, we mainly focus on its e-commerce platform operations. Specifically, the related information is acquired from the official websites of the company, well-known newspapers, and established magazines (e.g., Forbes, BBC, CNN, MIT Sloan Management Review, etc.). We also supplement the needed news from other websites to ensure completeness.

Based on the literature review and real case studies, we try to develop a "3As" framework assisting researchers and practitioners to understand the advantages of advanced technologies, as well as to achieve better implementations for the improvement of platform operations. Furthermore, based on the framework, we propose future directions for the application of technologies in platform operations. Overall, the research flow of this study is depicted in Fig. 3.

III. Product Selling Platforms

In this section, we review the existing literature that evaluates the application of advanced technologies in PS platforms. As discussed, all the PS platforms studied in the selected literature are two-sided, and we examine the selected studies according to the type of advanced technologies applied (i.e., big data and blockchain).

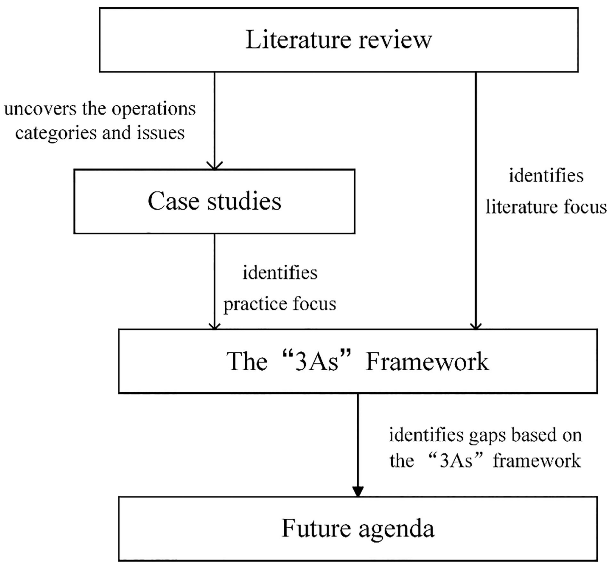

Fig. 3. Research flow of this article with real-world case studies.

A. Two-Sided PS Platforms

1) Big Data: Big data has been applied to improve the demand analytics of PS platforms, including consumer preferences and sales prediction. On the one hand, it is beneficial for PS platforms to analyze the information captured from the consumer side with the help of big data. For example, Chong *et al.* [18] analyze the data set of electronic products in Amazon.com to predict the sales trend. They evaluate the efficacy of two predictors (i.e., consumer online reviews and marketing promotion data) and find that consumer reviews demonstrate a stronger prediction ability. Some other studies also endeavor to enhance prediction by analyzing consumer online reviews [68], [93]. Different from Chong *et al.* [18], See-To and Ngai [68] focus on the sentimental reviews on Tmall. Specifically, the sentiments of consumers are classified into positive and negative types in See-To and Ngai [68]. Interestingly, consumer sentiments show little impact on the demand prediction of PS platforms [68]. Moreover, in addition to demand prediction, predicting product features and consumer preferences by excavating consumer reviewers is explored in Zhang *et al.* [93]. By applying the data of Amazon.com, the effectiveness of predicting product popularity trends by analyzing consumer reviewers is validated [93]. Most recently, Guo *et al.* [35] adopt data mining to enhance the prediction of consumer preferences by evaluating product ratings and consumer purchasing behaviors. On the other hand, it is widely acknowledged that the information collected from the seller side is also valuable for demand analysis. For instance, based on the sales data provided by eBay, Pilehvar *et al.* [59] empirically explore how the auction prices of similar products affect bidder behaviors.

2) Blockchain Technology: Notably, BT has been used to facilitate the use of information (UOI) for OM, such as information tracking and information transparency (disclosure). Additionally, information uncertainty always disturbs the operations of PS platforms. Therefore, we pay attention to the value of BT in improving the UOI in PS platforms in this subsection. On the one hand, BT is used to improve the operational transparency of PS platforms [29]. For instance, Choi [13] studies the value of BT in improving product transparency on a diamond selling platform. On this platform, consumers can track the source information of products, such as materials and the date of production. The author finds that it is beneficial to implement BT even though it incurs investment costs. Similarly, Shen *et al.* [70] analytically examine the effect of BT in improving information disclosure on a second-hand PS platform. They identify the optimal selling strategy with the consideration of BT implementation. On the other hand, BT has been deployed for information tracking and protection to improve the operations of PS platforms. For example, consumer willingness to trust rental platforms (e.g., Dou Bao Bo) can be enhanced with the implementation of BT, as consumers can track the rental information permanently in this case [14]. From the perspective of information security, Ranganthan *et al.* [62] empirically study the performance of a BT-based smart contract in solving user concerns about information security.

3) Additive Manufacturing: It is common that most AM-related platforms promote the sales of complex manufacturing products (e.g., 3-D printing). For instance, Sun *et al.* [76] focus on the sales of customized and normalized 3-D printing products. The authors explore the optimal pricing strategy and pricing power allocation by using the analytical modeling approach. In Sun *et al.* [76], the two platform sides are "consumers" and "designers" (e.g., design companies and individuals). The designers hold the pricing power together with the 3-D printing platform. The authors find that it is important to consider the quality difference between customized and normalized products to allocate pricing power and decide the optimal prices.

B. One-Sided and N-Sided PS Platforms

Studies on the operations of one-sided and n-sided PS platforms with the application of advanced technologies are relatively limited compared with two-sided PS platforms. Only one study [9] is identified through literature search. Specifically, for an n-sided PS platform, Cai *et al.* [9] study the implementation of BT in a platform-based supply chain, and they find that it is effective to overcome the moral hazard problem due to the improvement of information transparency achieved by BT. Considering the limited research efforts, it is essential for researchers to pay more attention to the relevant studies.

C. Discussion

Eleven studies have been reviewed and they can be divided into big data, BT, and AM from a technology-based perspective. Note that we summarize the discussed issues, research methods, details of methods, topics, and sides of the PS platforms reviewed in this section in Table O1 of Online Appendix A to depict the improvements of advanced technologies in platform operations. Based on the review, we find that the major effect of big data is to help PS platforms to better predict the characteristics of demand and help platforms to make customized selling decisions. Moreover, BT is an emerging technology that is usually applied to improve information transparency and track the information of products. Specifically, PS platforms need to implement BT when they transact with consumers who care about product information. Regarding the research methods, the review uncovers that closed-form analysis is the major research method employed for studying the role of BT, which differs from the literature focusing on the application of big data. We incorporate one study that explores the implementation of BT in a platform-based supply chain that involves the *n*-sided platform operations in Section III-B. Finally, one paper that explores the optimal pricing strategy of 3-D printing is reviewed.

IV. Service Platforms

Different from PS platforms, the major function of service platforms is to provide diverse services for users. To improve the operations of service platforms, advanced technologies play a crucial role as detailed below.

A. One-Sided Service Platforms

1) Big Data

Big data has been widely applied in improving the operations of two types of OS platforms: 1) DCS systems and 2) recommendation-related platforms, as reviewed in the following.

First, for real-time based DCS systems, it is a common challenge to deliver real-time responses to emergencies and disasters. To deal with this challenge, Fertier *et al.* [28] design a big data based automatic DCS system (e.g., emergency system) to enhance decisions under crises. In the system developed by Fertier *et al.* [28], real-time transportation information and road conditions are synchronized and analyzed to automatically generate dynamic decisions and cope with the emergency. Nagendra *et al.* [56] construct a DCS system that connects real-time weather and geographic information to provide real-time DCS for rescue teams. A case study based on real-world data is carried out to validate the performance of the proposed system [56].

Second, for recommendation-related platforms, big data analytics are useful to generate precise recommendations and provide reliable suggestions for individual users. It is especially important for content platforms (e.g., news platforms) to attract more users and thus expand markets through accurate recommendations. Accordingly, Zihayat *et al.* [96] propose a utility model to produce recommendations from the aspects of article level and the topic level recommendations separately by analyzing user clicking data. Real data are then applied to verify the performances of the proposed model [96]. Similarly, the accurate recommendation has been used in identifying experts in "online research social network platforms," such as ScholarMate [75]. In recent years, big data is combined with other tools to enhance recommendations. For example, Morente-Molinera *et al.* [55] propose that mobile technology, fuzzy ontology, and group decision-making can supplement imprecise data to derive recommendations for mobile app users. Furthermore, big data and deep learning are often combined to improve the efficiency and accuracy of prediction. For example, Jian *et al.* [40] examine the application of such a combination in cloud manufacturing platforms to improve performances in real practice.

2) Blockchain Technology: Notably, BT as a distributed ledger is recognized as a safe approach for information storage, making it an effective method to track information. For instance, BT has been used to track user behaviors in some emerging OS platforms (e.g., cloud manufacturing platforms). Aghamohammadzadeh and Fatahi Valilai [2] utilize the benefits of information security and transparency of BT to overcome the operational difficulties of cloud manufacturing platforms. The major difficulty refers to the enabling of task distribution in real time. In addition, Rahmanzadeh *et al.* [61] consider the application of BT in copyright protection, where BT can keep the detailed information of products displayed on the platform.

3) Other Technologies: In addition to the big data and BT reviewed above, other technologies, including IoT and AM (e.g., 3-D printing), have also been applied to help to improve OS platform operations.

Furthermore, IoT is a key component for Industry 4.0 toward achieving the connections of various elements. For example, it can connect diverse devices and aggregate data generated in real time. With this advantage, Rasouli [63] constructs a cloud manufacturing platform with the implementation of the IoT technology and evaluates the proposed platform through a case study. In addition to IoT, AM also attracts much attention from the academia as an innovative manufacturing approach. For instance, Rong *et al.* [66] conduct a case study to explore the optimal manufacturing strategy for a 3-D printing-based system with the aim of achieving ecosystem benefits.

Through the literature, we summarize how advanced technologies can be utilized to enhance the operations of OS platforms in the following. Note that a summary Table O2 is provided in Online Appendix A. We find that advanced technologies can be applied to improve the operations of OS platforms in diverse dimensions. First, big data is primarily used to improve DCS, including accurate recommendations and assistance for users' decision-making processes. Second, the existing literature focuses on exploring its efficacy in overcoming the difficulties in operating a centralized system and ensuring information security. Most of the related studies for the application of big data and BT in OS platforms are explored by developing solution algorithms (e.g., Bat scheduling algorithm and genetic algorithm), which shows that exploring methodological advancements is the mainstream research method in the domain.

Generally, for the literature on the implementation of big data, considerable research attention has been paid to data analytics to achieve DCS. Conversely, BT and IoT are mainly explored as effective technologies to overcome the inefficiency of information transmission and enhance device connection in developing cloud manufacturing platforms. Ultimately, note that most of the aforementioned studies carry out computational-based analysis to explore their research issues.

B. Two-Sided Service Platforms

Two-sided platforms refer to those that serve and connect two groups of users. For example, Microsoft X-Box is a famous video game platform that connects game developers and game players [25]. In the following, we discuss the implementations of advanced technologies in improving the operations of TS platforms in detail.

1) Big Data: Big data is employed by TS platforms (e.g., peer-to-peer (P2P) lending platforms, service supply chain platforms, and crowdfunding platforms) to examine the behaviors of two groups of users and provide further decision-making support. For instance, P2P lending platforms (wherein both the lenders and borrowers are platform users) can make an accurate prediction about the default risk by analyzing extensive user data on the mobile platform [52]. Furthermore, big data can be applied by TS platforms to launch price discrimination strategies by analyzing user purchasing habits [42], [48]. Liu *et al.* [48] reveal that this application is harmful for consumers in the service supply chain. However, Kathuria *et al.* [42] find that implementing price discrimination can help to entice the participation of service providers to join the platform. Behl *et al.* [6] empirically study the role of big data analytics (AI) in stimulating donation behaviors for a crowdfunding platform. By conducting a questionnaire survey and analyzing the collected data, the authors find that big data imposes a positive effect on the operational performance of the crowdfunding platform.

2) Blockchain Technology: Notably, BT has mainly been implemented in supply chain systems to improve information transparency and support information sharing [21], [82]. Specifically, De Giovanni [21] analytically reveals that it is cost-saving for the supply chain system to adopt BT to enhance the information transparency between suppliers and retailers during transactions. Similarly, Wang *et al.* [82] find that the implementation of BT is crucial to facilitate the data sharing and transaction of a marketplace, wherein the data of sellers (e.g., retailers and other information holders) are sold to data buyers (e.g., suppliers) effectively. Furthermore, with the advantages of BT in improving the security of information sharing, Vatankhah Barenji *et al.* [79] propose a BT-based system architecture and validate the value of BT in a manufacturing system. Moreover, BT can also be used to carry out behavior analysis in TS platforms. For example, Choi *et al.* [15] consider the function of BT in tracking the risk attitudes of consumers (e.g., risk-averse, risk-neutral, and risk-seeking) and explore the optimal pricing strategy for a TS platform.

3) Internet of Things: Similar to the implementation of IoT in OS platforms, IoT supports the operations of TS platforms from two aspects, namely, system integration and data collection. From the perspective of system connection, Reaidy *et al.* [64] study the implementation of IoT technology in a shared distribution platform for the integration of warehouses and retail stores. The authors propose a collaborative city hub system and reveal that the use of IoT can improve operational efficiency. Wang *et al.* [81] pay attention to the application of IoT in cloud manufacturing platforms. The authors validate the value of IoT in improving printing efficiency through the connection between 3-D printers and cloud manufacturing platforms. Meng *et al.* [53] explore the operational efficiency of an IoT-based network that links patients and medical professionals. The authors find that the implementation of IoT is able to reduce communication delay. From the perspective of data collection, Wu *et al.* [85] explore a parking location optimization problem for a shared parking platform that serves car users and parking space owners. In this platform, IoT is utilized to track the real-time information of accurate parking locations. Ng *et al.* [57] study the implementation of IoT in a mass customization service platform that bridges service providers and customers. The authors analytically explore the value of IoT in detecting consumer preferences.

Through the literature review, several findings can be generated. We summarize the operational issues, research methods, and topics of TS platform-related literature in Table O3 of Online Appendix A. First, big data is commonly applied to analyze the data of two-sided users so that the platform is able to support the decision-making of both sides. Second, BT has been implemented in various research areas, including the supply chain contract design, network design, and inventory management. From the perspective of research methodology, computational-based analysis is no longer the mainstream research method for exploring the values of BT compared with the studies related to OS platforms. Third, it is evident that IoT is the most widely adopted technology for supporting the operations of TS platforms. As a remark, the implementation of IoT involves various operation-based topics, such as sharing economy, warehousing, supply chain management, and medical system, owing to its essential role in data collection and system integration through advanced sensors.

C. N-Sided Service Platforms

Compared with OS and TS platforms, NS platforms serve more than two groups of users; thus, the interactions among groups become more complex. We discuss the value of advanced technologies for NS platforms in the following.

1) Big Data: Big data is crucial for NS platform operations from a UOI perspective. Accordingly, big data has been widely applied in social media platforms (e.g., Facebook and Twitter) that are typical examples of NS platforms. We review the related literature in the following. First, big data is applied to conduct user behavior analysis [1], [43], [51], [71] in social media platforms. For example, textual data (e.g., consumer reviews) are mined to present the trends of consumer word-of-mouth [1], [51], while the metadata (e.g., authors and follows) can be summarized and analyzed to reflect the social behavior of platform users [71]. For example, Ibrahim and Wang [39] explore the effect of user sentimental textual data on analyzing consumer preferences in various service segmentations, such as delivery and customer satisfaction. Ibrahim and Wang [39] find that it is effective for platforms to improve service levels with the help of big data. Kitchens *et al.* [43] explore the relationship between social media platforms and market consumption by using the collected data. The authors find that this relationship depends on the specific type of social media platforms.

Moreover, it is common that social media platform users adopt big data to achieve certain business goals, such as demand forecasting and profit prediction. However, it should be pointed out that this implementation of big data varies from that for production selling platforms because the beneficiaries are different. Here, social media platforms provide data as a service provider, while the beneficiaries are users of the social media platforms (e.g., product sellers). However, for PS platforms as reviewed in Section III, the beneficiaries are platforms. In terms of demand forecasting, Liu *et al.* [49] evaluate the effect of unstructured data analytics (e.g., text, video, etc.) on demand forecasting. They show that content quality and timeliness of data are effective prediction indicators. Similarly, in Yuan *et al.* [91], the sentiment data captured from Weibo (a famous Chinese social media platform) are analyzed to improve product demand prediction.

2) Blockchain Technology: Notably, BT mainly helps NS platforms in the UOI. First, BT is known to enhance information transparency to build trust among various parties. For example, Yu *et al.* [90] analytically examine the optimal guarantee mode of supply chain finance where BT is applied to facilitate information transparency. They find that the application of BT can realize systematic Pareto optimization, while consumer self-guarantee is the optimal mode. Second, as a distributed ledger, BT is able to improve information security. For instance, Rahman *et al.* [60] reveal that BT is able to ensure operational safety by identifying abnormal information for a cross-border cloud platform. Similarly, Yeh *et al.* [88] validate that the application of BT in IoT systems can deal with the challenge of information

TABLE III
FOUR SELECTED PLATFORM ENTERPRISES FROM FORBES LIST

Platform types	Enterprises	Rankings in Forbes list	References
Product selling platform (PS)	Amazon	4	Amazon.com, Forbes.com, and others.
One-sided service platform (OS)	SAP	22	Sap.com, Forbes.com, and others.
Two-sided service platform (TS)	PayPal	64	Paypal.com, Forbes.com, and others.
N-sided service platform (NS)	Facebook	5	Facebook.com, Forbes.com, and others.

security. In an invoice financing supply chain, Guerar *et al.* [33] utilize BT to design smart contracts. They find that the proposed BT-based platform is effective to address confidential problems and achieve information transparency. Last but not least, BT can improve information delivery in NS platforms. For instance, Dolgui *et al.* [23] demonstrate that with the accurate and timely information delivery by BT, the cyber–physical supply chain can achieve intelligent and automatic decision-making, as well as realize smart contracting. In addition, Tsoukalas and Falk [78] study the performance of a token-weight voting scheme in a BT-based platform. The authors analytically reveal that the token-weight voting scheme improves the overall voting quality.

We summarize the characteristics of the implementation of big data and BT by NS platforms in Table O4 of Online Appendix A. Evidently, the focal points are different. Specifically, the implementation of big data mainly concentrates on the analysis of user behavior by adopting computational and empirical analysis. However, BT has mainly been employed to facilitate the UOI, including information transparency, security, and delivery, by conducting computational-based analysis. Moreover, the research topics are different. Most of the studies related to big data explore the application in social media platforms, while there is no representative topic for the implementation of BT.

V. Real Case Studies

In this section, we present case studies to explore the real-world implementations of advanced technologies in various types of platforms. Following the method applied by Choi *et al.* [17], we select platform enterprises according to *The World's Most Valuable Brands 2020*[6] as evaluated by Forbes (for short Forbes List). Note that the listed enterprises have the needed abilities to adopt advanced technologies and are the pioneers to implement advanced technologies in specific industrial categories. From the list, we choose four platform enterprises—Amazon, SAP, PayPal, and Facebook—to represent the PS, OS, TS, and NS platforms, respectively (shown in Table III). To explore the implementation of advanced technologies, we search and summarize the related information in official websites and public news as introduced in Section II.[7] Moreover, to answer the research questions, during the search, we mainly pay attention to the information that is related to platform operations. Through the real cases, we expect readers to gain a deeper understanding of the current practices of advanced technologies in platform operations.

Before examining the industrial practices and conducting case studies, based on the findings in the literature review, we provide Table IV that summarizes the categories of operational

TABLE IV
CATEGORIES OF RESEARCH AND PRACTICAL ISSUES

Categories	Issues
Use of information (UOI)	Information prediction (UOI1)
	Information tracking (UOI2)
	Information transparency (UOI3)
	Information security (UOI4)
	Information delivery (UOI5)
Operating/Manufacturing processes (OMP)	Systems integration (OMP1)
	Manufacturing performance (OMP2)
Decision support (DCS)	Decision-making (DCS1)
	Accurate recommendation (DCS2)
Consumer behavior and marketing (CBM)	Behavior analysis (CBM1)
	Market expansion (CBM2)

issues. Specifically, four major categories have been identified, including the UOI, operating/manufacturing processes (OMPs), DCS, and consumer behavior and marketing (CBM). Among them, the study of UOI is relatively mature, and it comprises five operational issues, while other categories are the same, containing two issues. For the case studies, we discuss the implementation of advanced technologies by identifying the operational categories, as presented in Appendix B.[8]

VI. Implementation of Advanced Technologies

In this section, we summarize the implementation of advanced Industry 4.0 technologies in improving the platform operations from the perspectives of both the literature and real cases.

A. From Literature

Based on the literature review on the selected papers, it is evident that advanced technologies have been widely applied in two types of platforms, namely, the PS and service platforms. We summarize the implementations in these platforms and evaluate the similarities and differences between them in the following (provided in Table V).

Big data has been widely adopted by both the PS and service platforms. The major value of big data is the improvement of information prediction. Specifically, big data is applied by PS platforms (e.g., eBay, Amazon, and Tmall), TS platforms (e.g., P2P platform), and the users of NS platforms (e.g., social media platform) for demand forecasting. Furthermore, big data has attracted attention in conducting accurate decision-making and recommendation, especially vis-à-vis the implementation in OS

[6][Online]. Available: https://www.forbes.com/the-worlds-most-valuable-brands/#39ac63f6119c accessed on March 22, 2020.

[7]Sources to support case studies are provided in the Online Appendix B.

[8]We thank the reviewers for their recommendation that let us move the real cases into Appendix.

TABLE V
IDENTIFIED OPERATIONAL ISSUES IN THE LITERATURE REVIEW[9]

Technologies	Platforms	Issues
Big data	PS	Improving information prediction (UOI).
	OS	Helping with decision making (DCS1) and recommendation (DCS2).
	TS	Helping with information prediction (UOI1) and decision making (DCS1).
	NS	Conducting behavior analysis of users (CBM1) and improving information prediction (UOI1).
BT	PS	Improving information transparency (UOI3) and security (UOI4), and conducting information tracking (UOI2).
	OS	Ensuring information security (UO4).
	TS	Improving various uses of information (UOI2, UOI3, UOI4, UOI5).
	NS	Improving information delivery (UOI5), security (UOI4), and transparency (UOI3).
IoT	OS	Integrating devices (OMP1).
	TS	Enhancing systems integration (OMP1) and helping with information tracking (UOI2).
AM	PS	Improving manufacturing performance (OMP2).
	OS	Improving manufacturing performance (OMP2).

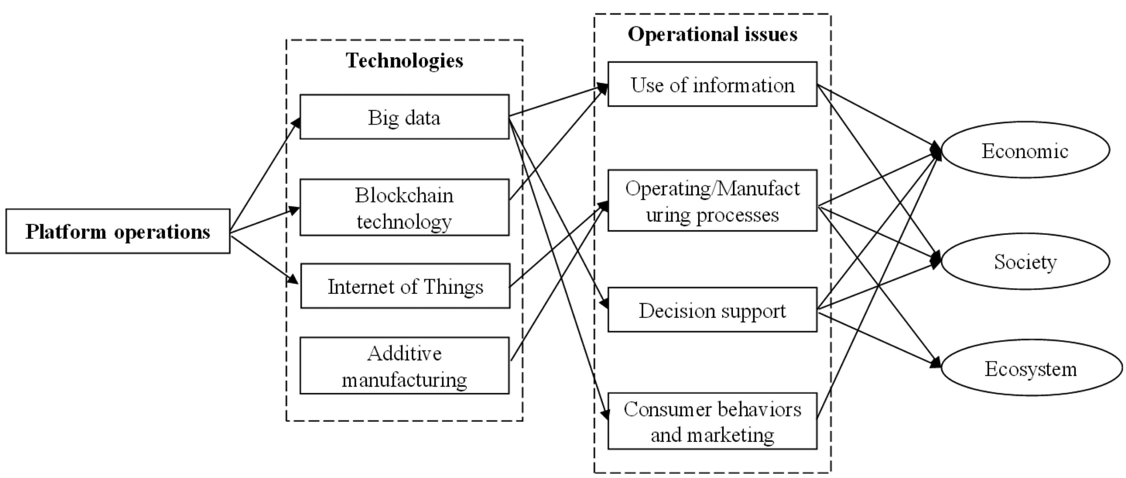

Fig. 4. Identified operational outcomes in the literature review.

platforms, such as DCS systems and recommendation systems, to improve decision accuracy.

Additionally, BT has been popularly implemented by both the PS and service platforms to improve the UOI. Note that information security is one of the most widespread challenging operational issues that can be addressed by using BT. For instance, BT helps to improve the security level of internal operations and protects the security of interactions among multisided operations. In addition, BT has promoted the transparent UOI for multisided platforms, including the PS, TS, and NS platforms, to enhance the operational efficiency among groups, while it has not been examined in OS platform-related studies. This finding reveals that BT contributes more to the value cocreation phenomenon for TS and NS platforms [30].

The adoption of IoT, especially the sensor connection and network connection, can remove the obstacles for cooperation among parties in technology-based service platforms (e.g., OS and TS). However, rare research analyzes the implementation of IoT in PS platforms. In the existing studies, most attention is paid to the implementation of IoT in TS platforms for the connection of systems. For instance, IoT can be utilized in 3-D printing-based cloud manufacturing platforms, medical management systems, and warehousing systems to connect platform parties for realizing system integration. Moreover, for OS platforms, IoT is implemented to improve operational efficiency.

Last but not least, the previous studies have validated the value of AM in platform operations even though the related research is limited. Notably, AM is usually adopted to facilitate manufacturing transformation and improve manufacturing performance. For example, 3-D printing, which is a typical realization of AM, has been considered in PS and OS platforms to carry out innovative manufacturing.

Based on the review above, we can depict the application of advanced technologies to improve platform operations and achieve good outcomes in three areas: economy, society, and ecosystem [46]. Specifically, the values of the four advanced technologies can be reflected in the improvements for four operational issues identified in the literature. Fig. 4 helps to demonstrate the findings. Note that the major efforts derived by improving platform operations focus on gaining economic

TABLE VI
IDENTIFIED OPERATIONAL TOPICS AND ISSUES IN REAL CASE STUDIES

Technologies	Enterprises	Common topics	Different topics
Big data	Amazon	Identifying fake products (UOI2).	Optimization of the searching engine (DCS2) and demand forecasting (UOI1).
	SAP	/	Improving the services of enterprise management software (UOI1, DSC1, CBM2).
	PayPal	Identifying fraudulent payment (UOI2).	Collaboration choice (UOI1, DCS1).
	Facebook	/	Optimization of advertising service (UOI1, CBM1, DSC1), and content recommendations (DCS2).
BT	Amazon	Optimization of product authentication (UOI2, UOI3).	/
	SAP	Optimization of product identification (UOI2).	Optimization of document transfers (UOI2, UOI3, UOI5).
	PayPal	Entering the cryptocurrency market (CBM2).	Improving service of the payments system (UOI4).
	Facebook	Entering the cryptocurrency market (CBM2, UOI4).	/
IoT	Amazon	Fulfillment of home smart devices (OMP1, CBM2).	/
	SAP	/	Optimization of equipment operations (UOI1, DCS1).
	PayPal	/	Fulfillment of e-payments (OMP1, CBM2).
	Facebook	Fulfillment of home smart devices (CBM2, UOI2, OMP1).	/
AM	Amazon	Improving the service level for Prime members (CBM2).	/

benefits in the Industry 4.0 era. However, social and ecological benefits are also the improvement goals that platforms would like to achieve.

B. From Real Cases and Practices

The four case studies presented above serve to investigate how different types of platform enterprises (e.g., PS, OS, TS, and NS) implement advanced technologies to improve their operations. Moreover, the case studies help to uncover the operational topics that advanced technologies are involved in, such as fake monitoring.

Overall, the implementation of advanced technologies has similarities and differences in the four enterprises. Specifically, big data, BT, and IoT are popular technologies that have been adopted by the four studied platform enterprises in improving operations. However, AM, as a production-oriented technology, is less attractive for platform enterprises. We see that only the PS platform, Amazon.com, considers selling 3-D printing products to expand the specific market. In the following, we discuss the implementation of big data, BT, IoT, as well as the identified operational issues in the case studies (provided in Table VI). Note that it is difficult to grasp the operational outcomes by reading the information on official websites and news. Therefore, we do not summarize the implementation outcomes in industrial practices.

Big data can be implemented in improving the UOI (e.g., UOI1) and DCS (e.g., DCS1) for the four types of platforms. It is interesting to observe that Amazon and PayPal use big data to identify fraudulent information to ensure trusted operations. This is because Amazon and PayPal are two-sided platforms that provide products or monetary transactions between groups. In this case, identifying fraudulent transactions is important to create a trustworthy image and achieve market expansion.

Different from the implementation of big data, BT contributes to the operations of platforms mainly in improving the UOI. Note that different types of platforms may utilize BT to cope with similar operational topics. For instance, it is observed that Amazon (PS) and SAP (OS) both implement BT to optimize their identification and authentication operations. For Amazon, this implementation improves the transactions between two sides, while it enhances the performance of intramural information transactions. Furthermore, PayPal (TS) and Facebook (NS) focus on the implementation of BT in the cryptocurrency market to create cryptocurrencies and enable the transactions of all types of cryptocurrencies. It shows that BT is the technical foundation of the development of cryptocurrency, and implementing BT can facilitate the expansion of the service scope of platforms.

Additionally, IoT has been widely implemented in connecting devices by various systems. On the one hand, IoT is implemented to help platform enterprises to expand the market and attract users. However, SAP (OS) implements IoT in improving interenterprise services, such as equipment testing and optimization, which differs from the implementation by other types of

[9]We provide TableO5 in Online Appendix A to indicate how the advanced Industry 4.0 technologies are used to address different operational issues statistically.

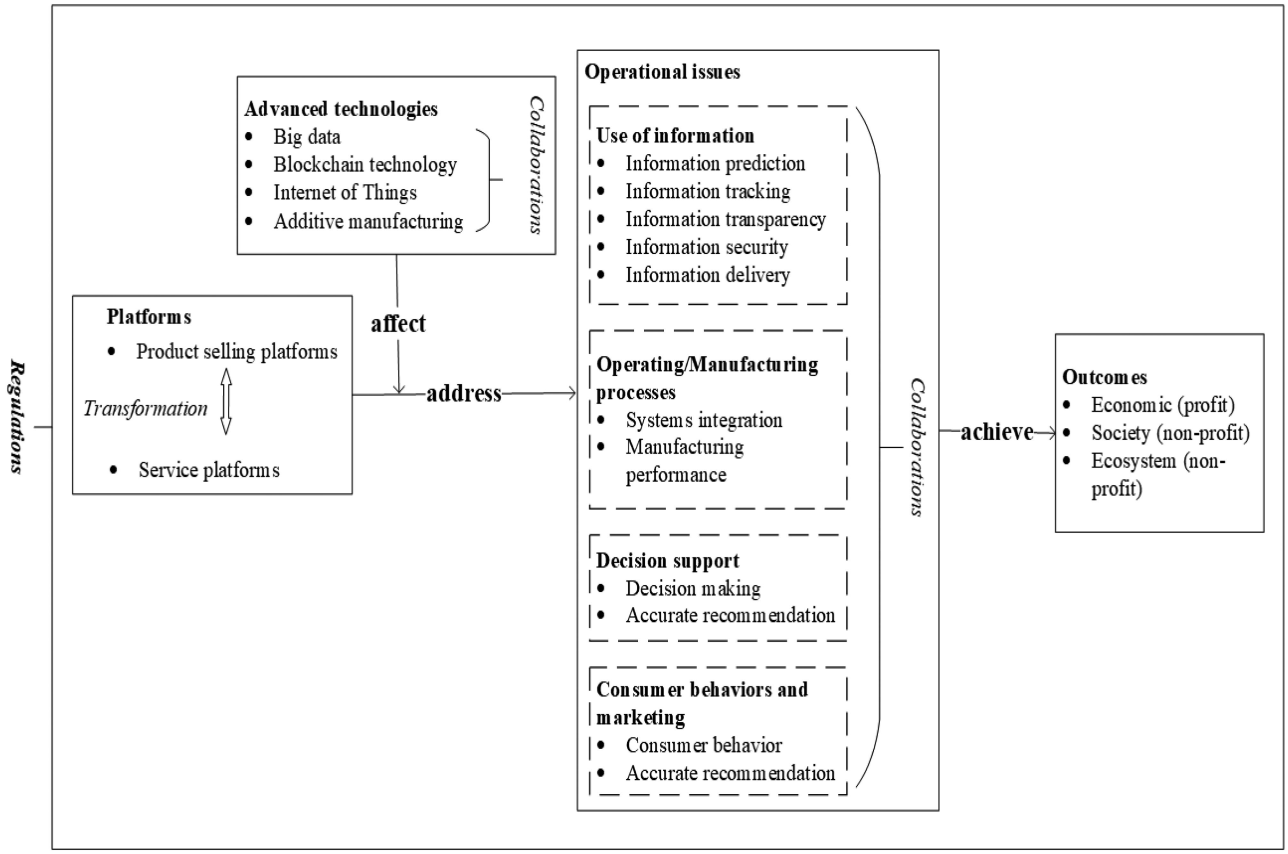

Fig. 5. The "3As" framework.

enterprises. On the other hand, similar to the implementation of BT, that of IoT has a resemblance in four types of platforms. Specifically, Amazon (PS) and Facebook (NS) devote themselves to explore the value of IoT upon entering the market of smart home devices.

VII. The "3As" Framework

Based on findings in the literature review and real case studies, we propose a framework that aims to indicate how platforms should "adopt" advanced technologies to "address" the operational issues to "achieve" the operational outcomes (as depicted in Fig. 5). Therefore, we call it the "3As" platform operations framework (the "3As" framework, for short). To address the research questions, we consider that this "3As" framework contains four components, including advanced technologies (component 1), platform operational issues (component 2), outcomes (component 3), and platforms (component 4). Based on the observations from the literature review and case studies, the "3As" framework also indicates three developments—collaborations, transformations, and regulations—to reveal the operational directions within each component and highlight the importance of regulations. Specifically, the *collaborations* development entails *technology* and *operational collaborations*, which are represented by the operations integrating two or more technologies and operational issues, respectively. Furthermore, the *transformations* development implies the change of platform types within the platform component. Moreover, the "3As" framework suggests that platform operations in the Industry 4.0 era impose a high demand for monitoring *regulations*. We introduce the three aforementioned developments (i.e., transformations, collaborations, and regulations) of the "3As" framework in the following.

Collaborations: On one hand, *technology collaborations* are common. From the discussion in Section VI, we see that, sometimes, the advanced technologies are applied by platforms alone (e.g., only big data or blockchain). Whereas, it is crucial for platforms to implement multiple technologies to support specific operational issues as pointed out by Olsen and Tomlin [58]. We call it *technology collaborations*, which means two or more technologies are integrated to support platform operations. The collaboration of advanced technologies enables further improvements for the performance of platforms. For example, "Big data and IoT" collaboration has been well-reported in the literature and practice for different platforms. In this combination, big data analytics is transformed to become physical devices oriented, which significantly differs from the sole implementation of big data technology. Specifically, in the "Big data and IoT" combination, IoT collects data from physical devices, while big data analyzes the collected data and provides the analysis results back to the IoT-based devices. For example, SAP launched a failure prediction project to monitor the working status of equipment. This project is conducted by using the "Big data and IoT" collaboration, where the operations data are collected from the IoT sensors. Similarly, "IoT and BT" collaboration has been applied in improving the management of information, such as enhancing information completeness and transparency in cloud-based platforms [60].

However, the operational categories are correlated, and we call it *operational collaborations*. It means that, with the help of technologies, platform operations can be improved in multiple operational categories. For instance, improvements in the UOI can lead to better performance in DCS, such as more accurate decision-making and recommendations. The UOI functions as a prerequisite to promote DCS, whereby information prediction and information tracking are the two major functions [55], [85]. The correlated improvements of operational categories can be viewed as operational collaborations.

Transformations: Driven by the wide implementations of technologies, it is crucial for platforms to conduct transformation and upgrading in the Industry 4.0 era. It not only includes the transformation of platform functions (between PS and service platforms) but also the sides of platforms (among OS, TS, and NS). From a function transformation perspective, it is observed that PS platforms are gradually putting more efforts into offering innovative services by implementing advanced technologies. For instance, Brynjolfsson *et al.* [8] explore the implementation of the AI translation service in eBay, a traditional PS platform, to support international trade. As revealed by Brynjolfsson *et al.* [8], eBay starts to transform from a onefold PS platform to a multifold platform that sells products and provides services. Furthermore, according to the case study of Facebook, we see that this enterprise provides a marketplace to sell products to local consumers with the help of big data analytics.[10] It means that Facebook, a typical service platform, intends to be a multifold platform by incorporating the PS function into the business structure. From the perspective of platform sides, many platforms are trying to expand their interfaces to connect more groups of users. For example, Rahman *et al.* [60] study the operations of a cloud platform, which provides data sharing services for *n*-sided groups of users instead of two sides by using IoT.

Regulations: The operations of platforms have been questioned by users, governments, the market, and other parties. With the implementation of advanced technologies, doubts are growing. This is because platforms become more powerful in certain operations, including information access and decision-making, once advanced technologies are applied. Regulations on platform operations are hence essential. In 2020, some countries and areas, such as the United States, European Union, United Kingdom, Japan, and China, released stricter regulations for digital platforms (e.g., Amazon, Facebook, and Google) [73]. These regulations will certainly affect the operational mode of platforms while preventing potential risks from various aspects, including 1) preventing the dominant force of platforms control in market competition [20], 2) reducing the leakage of user privacy, and 3) reducing illegal operations [47].

Observe that the “3As” framework is related to but different from the frameworks proposed in previous research. For example, Gawer [31] dissects the features of technological platforms from the perspective of the organizational continuum. In Gawer [31], three types of platforms (i.e., internal, supply chain, and industry platforms) are identified regarding different organizational forms, interfaces, accessible scope, and governance. Based on the discussion of platform types, Gawer [31] proposes a framework focusing on the interaction of innovation and competition along with the features of technical platforms. This framework aims to guide the operational strategies of collaboration, innovation, and competition for technological platforms [31]. Compared with the framework proposed by Gawer [31], the “3As” framework focuses on uncovering the implementation of advanced technologies in improving platform operations. More specifically, the “3As” framework applies a different platform classification paradigm from Gawer [31], as we categorize platforms according to functions and sides. Moreover, our “3As” framework differs from those exploring the implementation of advanced technologies in other domains. For instance, Kamble *et al.* [41] propose a framework to discuss the applications of Industry 4.0 technologies in achieving sustainable industries. As the focal domains are different, the components of the framework proposed by Kamble *et al.* [41] and our “3As” framework are distinct. The framework of Kamble *et al.* [41] focuses more on business integration by implementing Industry 4.0 technologies, while the “3As” framework pays more attention to the improvements of operational issues. Finally, the “3As” framework uncovers three developments to improve the “3As” operations in terms of strengthening the activities within components and providing guidance on policymaking.

To demonstrate the value of the proposed “3As” framework, we study how it can be applied in Amazon.com. We choose Amazon.com because it is an industrial giant with lots of public information. As we have conducted a relatively comprehensive case study on Amazon.com (see Appendix A), in this section, we focus on highlighting the related actions of Amazon.com on the proposed three developments under the “3As” framework.

Collaborations: Amazon.com has adopted the collaboration strategy to help enhance the sales opportunity and achieve economic outcomes. For instance, the “IoT and big data” collaboration can be witnessed in the use of Alexa in Amazon.com.

Transformations: Amazon.com has initiated the transformation from a standard two-sided PS platform to an *n*-sided PS platform. Similar to most e-commerce platforms, Amazon.com has launched Amazon Live, the live stream platform of Amazon.com. On this platform, instead of directly being linked with sellers, consumers are connected with influencers who promote products. With the development of live stream shopping, live stream selling will become one of the major features of Amazon.com.

Regulations: The authorities have been closely monitoring large e-commerce enterprises. Under the monitoring, Amazon.com has actively developed operational regulations in platform operations from the aspects of the global selling, consumer privacy protection, tax, and so on.

VIII. Future Agenda

In Sections III and IV, we conduct the literature review, which helps to identify the implementation of advanced technologies in four operational categories (i.e., “from literature”). Based on the identifications, we proceed to uncover the implementations of advanced technologies in industries (i.e., from real cases and practices). We summarize the literature and practical foci in Table VII and propose the future agenda based on the scientific observation of this table.

From Table VII, we can see four types of identifications, including the following:

1) overlaps of two foci;
2) single research focus;
3) single practice focus; and

[10][Online]. Available: https://www.facebook.com/business/marketplace accessed on April 8, 2021.

TABLE VII
TECHNOLOGIES AND THEIR IDENTIFIED OPERATIONAL ISSUES[12]

Technologies	**Platforms**	**Use of information**					**Operating/Manufacturing processes**		**Decision support**		**Consumer behavior and marketing**	
		UOI1	UOI2	UOI3	UOI4	UOI5	OMP1	OMP2	DCS1	DCS2	CBM1	CBM2
Big data	PS	O	Δ				*Agenda 1*			Δ		
	OS	Δ				√			O	√		Δ
	TS	O	Δ						O		√	
	NS	O							Δ	Δ	O	
BT	PS		O	O	√				*Agenda 2*			
	OS		Δ	Δ	√	Δ						
	TS		√	√	O	√						Δ
	NS			√	O	√						Δ
IoT	PS						Δ				*Agenda 3*	Δ
	OS	Δ					√		Δ			
	TS		√				O					Δ
	NS		Δ				Δ					Δ
AM	PS							√				Δ
	OS							√				*Agenda 4*
	TS											
	NS											

Remark: We use √ to denote the areas explored in the literature review, Δ denotes the areas being found in the real case studies, and O denotes the "overlaps" of explorations in both the literature review and real case studies.

4) "empty cells."

Note that the overlaps represent the implementations that have been studied in the literature and have been applied in practices. For instance, implementing big data analytics to predict information and generate accurate recommendations can be commonly observed in both the literature and case studies. Similarly, using BT to track information and improve information transparency for PS platforms are overlaps. Note that the implementations of the aforementioned 1), 2), and 3) have gained attention from academia and/or industries. For them, we may explore the possible innovations (e.g., collaborations, transformations, and regulations). More importantly, we focus on 4), i.e., "empty cells" to outline the future research directions for the implementations of advanced technologies.

Observing the "empty cells" shown in Table VII, we propose four future topics for enhancing the implementation of advanced technologies in platform operations.[11] Furthermore, the future agenda is proposed with the support of the "3As" framework (e.g., collaboration and transformation).

Big data (Agenda 1): More attention can be paid to the implementation of big data in improving manufacturing processes, such as systems integration and manufacturing performance enhancement. This is because big data, as an information-oriented technology, could provide suggestions by analyzing the historical data of manufacturing and system integrations. Supported by the big data based recommendations, platforms can hence make decisions related to the manufacturing processes in a timely manner. This will help to address operational issues and better achieve outcomes, especially in enhancing profit.

Blockchain technology (Agenda 2): According to the "3As" framework proposed, similar to big data, BT could be used to improve DCS performance. We can see that big data, as an information-oriented technology, can be used in improving the UOI and DCS. This *operational collaboration* inspires Agenda 2 for implementing BT in improving the DCS of platforms. For instance, it is meaningful for platforms to adopt blockchain-based smart contracts in supporting decision-making, which ensures the trackability and transparency of information. This implementation can effectively prevent possible fraudulent behaviors in the multiparty decision-making process [44].

Internet of Things (Agenda 3): Conventional wisdom always views IoT as the technology to facilitate physical networks. However, the technology collaborations of the "3As" framework reveal that IoT can be implemented together with big data to improve information tracking and information prediction. This implementation motivates us to explore the effect of the IoT implementation further in analyzing consumer behavior (by analyzing the collected consumer behavior data). For example, from the case study on Amazon, the intelligent voice assistant Alexa can be installed in various smart devices to record user behavior. The analysis of the behavior data would be useful to support platform strategies such as product promotion and pricing. In our "3As" framework, all these help to improve operational efficiency by better UOI and DCS, which ultimately generates benefits in both the economy and society.

Additive manufacturing (Agenda 4): AM is a manufacturing-based technology, which is mainly used to facilitate manufacturing using new materials. Moreover, AM can also play a critical role in improving the performance of PS and service platforms. Specifically, as an emerging technology, AM is a value-added service that can be employed by platforms to attract more consumers. Researchers and enterprises may further explore the approaches that platforms can adopt to incorporate AM into their operations. Taking SAP as an example, it may attract participants in AM chains to use its enterprise management software by

[11] Regarding the future research directions on how technology implementation can improve specific types of platforms, readers can refer to Table VI for more observations.

[12] We provide the findings obtained from the literature review and case studies as summarized in Table O5 and Table O6 in Online Appendix A.

TABLE VIII
MAJOR FINDINGS

Technologies implementations	- Big data and BT have been widely implemented by various platforms mainly focusing on the use of information. - By comparison, IoT and AM are less explored.
Platform operations	- The use of information and decision support are both important for PS platforms and service platforms. - Platforms are generally focusing on the enhancement of economic benefits in the Industry 4.0 era.
The "3As" framework	- Three developments, including transformations, collaborations, and regulations, are important for the "3As" framework.

incorporating AM-related services. This improves the OMPs in our "3As" framework, which yields better outcomes in both profit making and nonprofit making areas.

IX. Conclusion

With the growing importance of platform operations [83] and the increasing demand for the application of emerging technologies, the approach to implement advanced technologies in platforms becomes a crucial topic in the Industry 4.0 era. Examining the existing review papers related to this study, it can be observed that our research topic is still underexplored in platform operations. Motivated by the increasing importance of this topic and the potentials for further development, we conducted this study. Specifically, this article starts with a critical literature review on the studies exploring platform operations with the use of advanced technologies. From the literature review, we identified the important operational categories that can be improved by using advanced technologies, including the UOI, OMPs, DCS, and CBM for platforms. Second, we conducted case studies on four selected platform enterprises to generate more comprehensive insights on the implementation of advanced technologies. Third, we proposed the "3As" framework to depict the relationships among platforms, technologies, operational issues, and outcomes. We also revealed three developments under the "3As" framework that extensively reflect the implementation of advanced technologies. Finally, we generated future agenda that may inspire further explorations. The major findings of this study are summarized in the following. To better demonstrate the findings, we provide Table VIII that concisely summarizes the major findings.

Technologies implementations: We uncover the implementation of major advanced technologies to support platform operations in Industry 4.0 (which answers *Research Question 1* proposed in Section I-B). Big data and BT have been employed by four types of platforms (PS, OS, TS, and NS) in improving the UOI. Specifically, the implementation of big data mainly focuses on information prediction and information tracking. Conversely, BT has been mainly applied to guarantee information transparency, security, and smooth delivery. However, IoT and AM have attracted less attention compared with big data and BT. For the implementation of IoT, it is interesting to observe that IoT has been used to collect data and serve for the UOI. This implementation is different from its common use in connecting systems; AM is an innovative manufacturing technology that can be considered by platforms to add service value.

Platform operations: We find that platform operations can be significantly improved in various aspects with the help of advanced technologies (which answers *Research Question 2* proposed in Section I-B). For example, it is important for PS and service platforms to pay attention to improving the UOI and DCS in the Industry 4.0 era. Furthermore, platforms are generally focusing on the enhancement of economic benefits by implementing advanced technologies, which are independent of the platform types (which answers the *Research Question 3* in Section I-B).

The "3As" framework: We propose a "3As" framework to illustrate the relationships among platforms, advanced technologies, operational issues, and outcomes (which answers *Research Question 4* in Section I-B). This framework provides guidance for platforms on how to adopt advanced technologies to address the operational issues in achieving different outcomes. Moreover, the three types of developments uncovered, including correlations, transformations, and regulations, extend the "3As" framework and help to gain a deeper understanding of platform operations in the Industry 4.0 era. For instance, the "3As" framework proposes that technology collaborations among different technologies can enhance the performance of technologies implementation.

In conclusion, platform operations have attracted tremendous attention from both academia and the industry. The application of advanced technologies has brought opportunities and challenges to platform operations in the Industry 4.0 era. Both academics and enterprises have been exploring the developments of platform operations in the Industry 4.0 era, and various technologies have been examined over the past decade. However, there is still a large room for further explorations as identified in the future agenda. For instance, it is important to study the implementation of big data in improving manufacturing processes. In addition to platform operations, as we know, technology is increasingly used in various industries. Therefore, exploring its development and implementation in other areas, such as environmental sustainability [24] and sharing economy-based operations [3], deserves attention. In addition to the implementation of technologies, other topics for platform operations will also be interesting to study. These include cybersecurity [12], [50] and government regulations [73]. We believe that this article can lay a foundation for the research on platform operations in the Industry 4.0 era, as well as help to inspire more studies in the future.

Appendix A
Details of Real Cases

A.1. Amazon: Amazon is a cross-border e-commerce enterprise. As reported, the largest proportion of the overall revenue for Amazon is generated through e-commerce sales in 2020, reaching US$ 197.35 billion. This means that the e-commerce platform service has become the core business of Amazon. In recent years, with the development of the Industry 4.0 era, Amazon.com has involved advanced technologies in its operations. We discuss the implementations successively in the following.

Big data: Big data, including big data analytics, has been implemented to extract the value of the large amount of data stored in Amazom.com. With the use of big data, Amazon.com optimizes its search engine by providing customized search results for consumers (DSC2). Furthermore, big data analytics would help sellers to achieve accurate sales forecasting (UOI1), such as sales amount, trends, and pricing, to enhance profit. However, it is necessary for Amazon.com to fight against fake products to enhance operational reliability. Therefore, Amazon has announced the "Project Zero" service project, wherein the deep learning approach is employed to monitor products and delete fake products (UOI2).

BT: BT has been used to improve information storage and tracking for the retail operations of Amazon.com. For example, Amazon.com has launched the "Transparency Service" project that aims to guarantee the authenticity of products for consumers (UOI3). In this "Transparency Service" project, to ensure authenticity, products are shipped with specific codes on packing boxes for identification, which will further induce market consumption. Moreover, blockchain can be applied to track product information (UOI2), including production, storage, and delivery, which improves operational efficiency.

IoT: IoT helps Amazon.com boost sales by enhancing the sales opportunity. For example, Amazon's Alexa is an IoT-based intelligent voice assistant that enables consumers to purchase products on Amazon.com by talking to Alexa (e.g., voice purchasing). Specifically, when consumers place orders through the voice purchasing function, the order missions are processed by the Alexa app that connects Alexa through Bluetooth (OMP1). Therefore, the implementation of IoT has the potential to stimulate consumers to make orders on Amazon.com (CBM2).

AM: Amazon.com is able to expand the market by incorporating AM into its platform business. For instance, Amazon.com offers a specific market to sell 3-D printing products. With this market, Amazon.com stimulates the users of both sides (e.g., consumers and brands). Additionally, Amazon.com provides the 3-D products delivery service to prime members to leverage the proportion of high-level consumers (prime members) (CBM2).

A.2. SAP: SAP is a well-known software enterprise that provides services to manage internal operations, such as enterprise resources and consumer relations. In the Industry 4.0 era, SAP has implemented advanced technologies to achieve the upgrading of its software and services. For example, SAP reported how it implemented advanced technologies (e.g., big data, blockchain, IoT, etc.) in September 2020. We summarize the implementations revealed from this report and other information sources in the following.

Big data: The key feature of enterprise management software is the ability to store and handle massive data. In this case, the adoption of big data is valuable. Specifically, SAP has proposed the "Agile Big Data" concept that is about distilling the processes of using big data to support the operations and decisions of enterprises. Typical applications include: 1) improving the use of data to prevent emergencies and predict major events of enterprise operations (UOI1); 2) providing decision suggestions through the analytics of historical data (DCS1); and 3) improving service quality to achieve business expansions (CBM2). In addition, SAP proposes a "Big Data Warehousing" project aiming to process data streaming and improve data extraction. With this implementation, SAP can provide timely warehousing management suggestions (DCS1) for managers.

BT: BT is mainly used by SAP to improve the UOI, especially for document transfer and information identification. Specifically, for enterprise management, documents are generally transferred manually among multilevel departments. The implementation of the secure ledger (i.e., BT) guarantees the transparency (UOI3) and trackability (UOI2) of the documents transferred (UOI5) in systems. Furthermore, BT has been applied to support the identification work. Taking an example from the food industry, Bumble Bee Food cooperated with SAP in tracking fresh seafood sources (UOI2) by using BT to ensure the reliability of identification, thus enhancing consumer trust.

IoT: In recent years, SAP has started to use IoT technology in various types of service projects to improve system operations. For example, in the "SAP Predictive Asset Insights," the working data of connected equipment are recorded by sensors, which enables the data analytics to predict malfunction (UOI1) and optimize workload (DCS1). Note that big data analytics is always considered as the driving force of the implementation of IoT. This is because big data analytics can expand the value of IoT implementation in terms of generating in-depth decision-making support (DCS1) based on sensor data.

A.3. PayPal: PayPal is a third-party payment service provider that serves vendors and individual users for e-transfers and e-payments. It is a TS platform that bridges payers and payees and has become one of the most popular online payment platforms in the United States. In the Industry 4.0 era, PayPal pays attention to the implementation of advanced technologies because the operations of online payment platforms have especially high technological requirements.

Big data: Big data is mainly used to improve user experiences by analyzing the huge amount of recorded payment data. Specifically, PayPal has been actively combating fraudulent payments with the help of big data. Here, the role of big data is to identify and block fraudulent information (UOI2) by mining historical data (e.g., learning the features of normal and fraudulent payments). In addition, based on the data analytics, PayPal can select vendors who have a large volume of online payments to cooperate (DCS1). Moreover, big data can be implemented to predict vendor behavior, such as credit (UOI1).

BT: BT motivates the use of cryptocurrency and helps with payment security. Since 2020, PayPal has started allowing consumers to use Bitcoin for e-payments, where Bitcoin is a cryptocurrency based on BT. Upon entering the Bitcoin market, PayPal expands its business to the cryptocurrency-enabled platform (CBM2) that potentially increases the volume of payments. Additionally, BT has been implemented for payment security. For instance, on March 8, 2021, PayPal has acquired a cloud-based

TABLE IX
LIST OF SELECTED JOURNALS

Annals of Operations Research, Decision Sciences, Decision Support Systems, European Journal of Operational Research, International Journal of Production Economics, Information Systems Journals, Information Systems Research, IEEE Transactions on Engineering Management, International Journal of Production Research, Management Science, Manufacturing & Service Operations Management, Marketing Science, MIS Quarterly, Journal of Management Information Systems, Journal of Operations Management, Omega, Production and Operations Management, Transportation Research of Part E: Logistics and Transportation Review.

company, Curv, which develops BT to keep secure payments (UOI4) with the help of multiparty computation protocols.

IoT: As a mobile payment platform, PayPal serves not only online vendors but also offline vendors. IoT plays a role to expand the market of e-payments for offline transactions (CBM2). Specifically, PayPal develops the PayPal Commerce platform that enables consumer e-payments in physical stores using IoT devices (OMP1), such as mobile phones and smart bracelets, in stores.

A.4. Facebook: Facebook is a social media platform that operates as an NS platform that connects users, advertisers, third-party content producers, and other groups [37]. The monthly active users of Facebook were approximately 2.8 billion in 2020.[13] Owing to the large number of users, the high variety of participants, and the high complexity of operations, it is crucial for Facebook to proactively implement advanced technologies to achieve better success in the Industry 4.0 era.

Big data: Having a huge amount of user data is a hallmark of Facebook, and it creates opportunities for platform operations. First, as an NS platform, big data helps Facebook to analyze user behavior (CBM1) and provides expanded services. For example, targeting advertisement service is one of the most representative services, which indicates that Facebook helps advertisers to find accurate targeting customers with the use of big data analytics (UOI1 and DCS1). It is effective for Facebook to attract advertisers by conducting user behavior analytics. Moreover, big data can be used to dig out the preference of users, thus providing customized recommendations. For instance, Facebook establishes a “like button” function to collect consumer preferences. Through the analysis of the data collected from the “like button,” Facebook can be aware of how to recommend news, advertisements, and friends that the user may be interested in (DCS2).

BT: It is observed that Facebook has devoted itself to entering the cryptocurrency market (CBM2). In June 2019, Facebook announced the Libra Project. In this project, Facebook cryptocurrency can be developed with the support of BT. The implementation of BT not only enables the use of cryptocurrency but also supports decentralized transactions among participants in a secure platform (UOI4).

IoT: Similar to the implementation of IoT in Amazon, Facebook is planning to implement IoT in intelligent devices. Specifically, Facebook develops intelligent devices, such as lightbulbs and fridges, which support the communication of Facebook users through talking to these devices. In this circumstance, IoT is applied to connect devices in the system (OMP1). Furthermore, Facebook started to develop its own home smart devices, including home video in 2017 and chips in 2018. The mentioned developments regarding intelligent devices can expand the market of Facebook by attracting more users who are interested in using intelligent devices (CBM2). Finally, the implementation of IoT facilitates high-level user analyses, especially as more accurate user preferences can be obtained from intelligent devices (UOI2), which then leads to an increase in the quality of the advertisement service.

[13][Online]. Available: https://www.statista.com/topics/751/facebook/ accessed on April 2, 2021.

APPENDIX B
LIST OF SELECTED JOURNALS AND ABBREVIATIONS

See Tables IX and X.

TABLE X
ABBREVIATIONS OF PLATFORM TYPES AND ADVANCED TECHNOLOGIES

Abbreviations	Full forms
PS	Product selling
OS	One-sided service
TS	Two-sided service
NS	N-sided service
AM	Additive manufacturing
IoT	Internet of things
BT	Blockchain technology
OM	Operations management
IS	Information science

REFERENCES

[1] P. Adamopoulos, A. Ghose, and V. Todri, “The impact of user personality traits on word of mouth: Text-mining social media platforms,” *Inf. Syst. Res.*, vol. 29, no. 3, pp. 612–640, 2018.

[2] E. Aghamohammadzadeh and O. Fatahi Valilai, “A novel cloud manufacturing service composition platform enabled by blockchain technology,” *Int. J. Prod. Res.*, vol. 58, no. 17, pp. 5280–5298, 2020.

[3] S. Asian, A. Hafezalkotob, and J. J. John, “Sharing economy in organic food supply chains: A pathway to sustainable development,” *Int. J. Prod. Econ.*, vol. 218, pp. 322–338, 2020.

[4] V. Babich and G. Hilary, “OM forum—Distributed ledgers and operations: What operations management researchers should know about blockchain technology,” *Manuf. Service Operations Manage.*, vol. 22, no. 2, pp. 223–240, 2020.

[5] S. Bag, S. Gupta, T. M. Choi, and A. Kumar, “Roles of innovation leadership on using big data analytics to establish resilient healthcare supply chains to combat the COVID-19 pandemic: A multimethodological study,” *IEEE Trans. Eng. Manage.*, to be published, doi: 10.1109/TEM.2021.3101590.

[6] A. Behl, P. Dutta, Z. Luo, and P. Sheorey, "Enabling artificial intelligence on a donation-based crowdfunding platform: A theoretical approach," in *Annals of Operations Research*. Berlin, Germany: Springer, 2021.
[7] S. Benjaafar and M. Hu, "Operations management in the age of the sharing economy: What is old and what is new," *Manuf. Service Operations Manage.*, vol. 22, no. 1, pp. 93–101, 2020.
[8] E. Brynjolfsson, X. Hui, and M. Liu, "Does machine translation affect international trade? Evidence from a large digital platform," *Manage. Sci.*, vol. 65, no. 12, pp. 5449–5460, 2019.
[9] Y. J. Cai, T. M. Choi, and J. Zhang, "Platform supported supply chain operations in the blockchain era: Supply contracting and moral hazards," *Decis. Sci.*, vol. 52, no. 4, pp. 866–892, 2020.
[10] A. Caporuscio, P. Moran, and M. Simoni, "Complexity induced risks posed by upcoming digital ultra-platforms: An agent-based simulation model," *IEEE Trans. Eng. Manage.*, to be published, doi: 10.1109/TEM.2021.3096634.
[11] Y. J. Chen *et al.*, "OM forum—Innovative online platforms: Research opportunities," *Manuf. Service Operations Manage.*, vol. 22, no. 3, pp. 430–445, 2020.
[12] K. F. Cheung, M. G. H. Bell, and J. Bhattacharjya, "Cybersecurity in logistics and supply chain management: An overview and future research directions," *Transp. Res. Part E: Logistics Transp. Rev.*, vol. 146, no. 2, 2020, Art. no. 102217.
[13] T. M. Choi, "Blockchain-technology-supported platforms for diamond authentication and certification in luxury supply chains," *Transp. Res. Part E: Logistics Transp. Rev.*, vol. 128, pp. 17–29, 2019.
[14] T. M. Choi, L. Feng, and R. Li, "Information disclosure structure in supply chains with rental service platforms in the blockchain technology era," *Int. J. Prod. Econ.*, vol. 221, 2020, Art. no. 107473.
[15] T. M. Choi, S. Guo, N. Liu, and X. Shi, "Optimal pricing in on-demand-service-platform-operations with hired agents and risk-sensitive customers in the blockchain era," *Eur. J. Oper. Res.*, vol. 284, no. 3, pp. 1031–1042, 2020.
[16] T. M. Choi, S. Kumar, X. Yue, and H. L. Chan, "Disruptive technologies and operations management in the industry 4.0 era and beyond," in *Production and Operations Management*. Hoboken, NJ, USA: Wiley, 2021.
[17] T. M. Choi, S. W. Wallace, and Y. Wang, "Big data analytics in operations management," *Prod. Operations Manage.,* vol. 27, no. 10, pp. 1868–1883, 2018.
[18] A. Y. L. Chong, E. Ch'ng, M. J. Liu, and B. Li, "Predicting consumer product demands via big data: The roles of online promotional marketing and online reviews," *Int. J. Prod. Res.*, vol. 55, no. 17, pp. 5142–5156, 2017.
[19] S. Croom, P. Romano, and M. Giannakis, "Supply chain management: An analytical framework for critical literature review," *Eur. J. Purchasing Supply Manage.*, vol. 6, no. 1, pp. 67–83, 2000.
[20] D. Cutolo, A. Hargadon, and M. Kenney, "Competing on platforms," *MIT Sloan Manage. Rev.*, 2021. [Online]. Available: https://sloanreview.mit.edu/article/competing-on-platforms/
[21] P. De Giovanni, "Blockchain and smart contracts in supply chain management: A game theoretic model," *Int. J. Prod. Econ.*, vol. 228, 2020, Art. no. 107855.
[22] U. M. Dilberoglu, B. Gharehpapagh, U. Yaman, and M. Dolen, "The role of additive manufacturing in the era of industry 4.0," *Procedia Manuf.*, vol. 11, pp. 545–554, 2017.
[23] A. Dolgui, D. Ivanov, S. Potryasaev, B. Sokolov, M. Ivanova, and F. Werner, "Blockchain-oriented dynamic modelling of smart contract design and execution in the supply chain," *Int. J. Prod. Res.*, vol. 58, no. 7, pp. 2184–2199, 2020.
[24] S. Du, L. Wang, L. Hu, and Y. Zhu, "Platform-led green advertising: Promote the best or promote by performance," *Transp. Res. Part E: Logistics Transp. Rev.*, vol. 128, pp. 115–131, 2019.
[25] T. Eisenmann, G. Parker, and M. W. Van Alstyne, "Strategies for two-sided markets," *Harvard Bus. Rev.*, vol. 84, no. 10, 2006, Art. no. 92.
[26] A. L. F. Facin, L. A. de Vasconcelos Gomes, M. de Mesquita Spinola, and M. S. Salerno, "The evolution of the platform concept: A systematic review," *IEEE Trans. Eng. Manage.*, vol. 63, no. 4, pp. 475–488, Nov. 2016.
[27] A. Felsberger and G. Reiner, "Sustainable industry 4.0 in production and operations management: A systematic literature review," *Sustainability*, vol. 12, no. 19, 2020, Art. no. 7982.
[28] A. Fertier, A.-M. Barthe-Delanoë, A. Montarnal, S. Truptil, and F. Bénaben, "A new emergency decision support system: The automatic interpretation and contextualisation of events to model a crisis situation in real-time," *Decis. Support Syst.*, vol. 133, no. 1, 2020, Art. no. 113260.
[29] K. Francisco and D. Swanson, "The supply chain has no clothes: Technology adoption of blockchain for supply chain transparency," *Logistics*, vol. 2, no. 1, 2018, Art. no. 2.
[30] W. Fu, Q. Wang, and X. Zhao, "Platform-based service innovation and system design: A literature review," *Ind. Manage. Data Syst.*, vol. 118, no. 5, pp. 946–974, 2018.
[31] A. Gawer, "Bridging differng perspectives on technological platforms: Toward an integrative framework," *Res. Policy*, vol. 43, no. 7, pp. 1239–1249, 2014.
[32] A. Gawer, "Digital platforms' boundaries: The interplay of firm scope, platform sides, and digital interfaces," *Long Range Plan.*, vol. 54, no. 5, 2020, Art. no. 102045.
[33] M. Guerar, A. Merlo, M. Migliardi, F. Palmieri, and L. Verderame, "A fraud-resilient blockchain-based solution for invoice financing," *IEEE Trans. Eng. Manage.*, vol. 67, no. 4, pp. 1086–1098, Nov. 2020.
[34] S. Guha and S. Kumar, "Emergence of big data research in operations management, information systems, and healthcare: Past contributions and future roadmap," *Prod. Operations Manage.*, vol. 27, no. 9, pp. 1724–1735, 2018.
[35] M. Guo, X. Liao, J. Liu, and Q. Zhang, "Consumer preference analysis: A data-driven multiple criteria approach integrating online information," *Omega*, vol. 96, 2020, Art. no. 102074.
[36] S. Guo, T. M. Choi, and S. H. Chung, "Self-design fun: Should 3D printing be employed in mass customization operations?," *Eur. J. Oper. Res.*, 2021. [Online]. Available: https://doi.org/10.1016/j.ejor.2021.07.009
[37] A. Hagiu, "Strategic decisions for multisided platforms," *MIT Sloan Manage. Rev.*, vol. 55, no. 2, 2014, Art. no. 71.
[38] A. Hagiu and J. Wright, "Multi-sided platforms," *Int. J. Ind. Org.*, vol. 43, pp. 162–174, 2015.
[39] N. F. Ibrahim and X. Wang, "A text analytics approach for online retailing service improvement: Evidence from Twitter," *Decis. Support Syst.*, vol. 121, pp. 37–50, 2019.
[40] C. Jian, J. Ping, and M. Zhang, "A cloud edge-based two-level hybrid scheduling learning model in cloud manufacturing," *Int. J. Prod. Res.*, vol. 59, no. 16, pp. 1–15, 2020.
[41] S. S. Kamble, A. Gunasekaran, and S. A. Gawankar, "Sustainable industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives," *Process Saf. Environ. Protection*, vol. 117, pp. 408–425, 2018.
[42] A. Kathuria, P. P. Karhade, and B. R. Konsynski, "In the realm of hungry ghosts: Multi-level theory for supplier participation on digital platforms," *J. Manage. Inf. Syst.*, vol. 37, no. 2, pp. 396–430, 2020.
[43] B. Kitchens, S. L. Johnson, and P. Gray, "Understanding echo chambers and filter bubbles: The impact of social media on diversification and partisan shifts in news consumption," *MIS Quart.*, vol. 44, no. 4, pp. 1619–1649, 2020.
[44] A. Kosba, A. Miller, E. Shi, Z. Wen, and C. Papamanthou, "Hawk: The blockchain model of cryptography and privacy-preserving smart contracts," in *Proc. IEEE Symp. Secur. Privacy*, 2016, pp. 839–858.
[45] N. Lakemond, G. Holmberg, and A. Pettersson, "Digital transformation in complex systems," *IEEE Trans. Eng. Manage.*, to be published, doi: 10.1109/TEM.2021.3118203.
[46] Y. Li, J. Dai, and L. Cui, "The impact of digital technologies on economic and environmental performance in the context of industry 4.0: A moderated mediation model," *Int. J. Prod. Econ.*, vol. 229, 2020, Art. no. 107777.
[47] B. Libert, M. Beck, and G. Calapai, "With great platforms comes great responsibility," *MIT Sloan Manage. Rev.*, 2018. [Online]. Available: https://sloanreview.mit.edu/article/with-great-platforms-comes-great-responsibility/
[48] W. Liu, S. Long, D. Xie, Y. Liang, and J. Wang, "How to govern the big data discriminatory pricing behavior in the platform service supply chain? An examination with a three-party evolutionary game model," *Int. J. Prod. Econ.*, vol. 231, 2021, Art. no. 107910.
[49] X. Liu, P. V. Singh, and K. Srinivasan, "A structured analysis of unstructured big data by leveraging cloud computing," *Marketing Sci.*, vol. 35, no. 3, pp. 363–388, 2016.
[50] S. Luo and T. M. Choi, "E-commerce supply chains with considerations of cyber-security: Should governments play a role?," *Prod. Operations Manage.*, to be published, doi: 10.1111/poms.13666.
[51] J. Ma, Y. K. Tse, X. Wang, and M. Zhang, "Examining customer perception and behaviour through social media research–An empirical study of the united airlines overbooking crisis," *Transp. Res. Part E: Logistics Transp. Rev.*, vol. 127, pp. 192–205, 2019.

[52] L. Ma, X. Zhao, Z. Zhou, and Y. Liu, "A new aspect on P2P online lending default prediction using meta-level phone usage data in China," *Decis. Support Syst.*, vol. 111, pp. 60–71, 2018.
[53] W. Meng, W. Li, and L. Zhu, "Enhancing medical smartphone networks via blockchain-based trust management against insider attacks," *IEEE Trans. Eng. Manage.*, vol. 67, no. 4, pp. 1377–1386, Nov. 2020.
[54] S. Menon and K. Jain, "Blockchain technology for transparency in agri-food supply chain: Use cases, limitations, and future directions," *IEEE Trans. Eng. Manage.*, to be published, doi: 10.1109/TEM.2021.3110903.
[55] J. A. Morente-Molinera, R. Wikström, E. Herrera-Viedma, and C. Carlsson, "A linguistic mobile decision support system based on fuzzy ontology to facilitate knowledge mobilization," *Decis. Support Syst.*, vol. 81, pp. 66–75, 2016.
[56] N. P. Nagendra, G. Narayanamurthy, and R. Moser, "Management of humanitarian relief operations using satellite big data analytics: The case of Kerala floods," in *Annals of Operations Research*. Ipswich, MA, USA: EBSCO, 2020.
[57] I. Ng, K. Scharf, G. Pogrebna, and R. Maull, "Contextual variety, Internet-of-Things and the choice of tailoring over platform: Mass customisation strategy in supply chain management," *Int. J. Prod. Econ.*, vol. 159, pp. 76–87, 2015.
[58] T. L. Olsen and B. Tomlin, "Industry 4.0: Opportunities and challenges for operations management," *Manuf. Service Operations Manage.*, vol. 22, no. 1, pp. 113–122, 2020.
[59] A. Pilehvar, W. J. Elmaghraby, and A. Gopal, "Market information and bidder heterogeneity in secondary market online B2B auctions," *Manage. Sci.*, vol. 63, no. 5, pp. 1493–1518, 2017.
[60] M. S. Rahman *et al.*, "Accountable cross-border data sharing using blockchain under relaxed trust assumption," *IEEE Trans. Eng. Manage.*, vol. 67, no. 4, pp. 1476–1486, Nov. 2020.
[61] S. Rahmanzadeh, M. S. Pishvaee, and M. R. Rasouli, "Integrated innovative product design and supply chain tactical planning within a blockchain platform," *Int. J. Prod. Res.*, vol. 58, no. 7, pp. 2242–2262, 2020.
[62] V. P. Ranganthan, R. Dantu, A. Paul, P. Mears, and K. Morozov, "A decentralized marketplace application on the ethereum blockchain," in *Proc. IEEE 4th Int. Conf. Collaboration Internet Comput.*, 2018, pp. 90–97.
[63] M. R. Rasouli, "An architecture for iot-enabled intelligent process-aware cloud production platform: A case study in a networked cloud clinical laboratory," *Int. J. Prod. Res.*, vol. 58, no. 12, pp. 3765–3780, 2020.
[64] P. J. Reaidy, A. Gunasekaran, and A. Spalanzani, "Bottom-up approach based on internet of things for order fulfillment in a collaborative warehousing environment," *Int. J. Prod. Econ.*, vol. 159, pp. 29–40, 2015.
[65] J.-C. Rochet and J. Tirole, "Platform competition in two-sided markets," *J. Eur. Econ. Assoc.*, vol. 1, no. 4, pp. 990–1029, 2003.
[66] K. Rong, Y. Lin, J. Yu, and Y. Zhang, "Manufacturing strategies for the ecosystem-based manufacturing system in the context of 3D printing," *Int. J. Prod. Res.*, vol. 58, no. 8, pp. 2315–2334, 2020.
[67] S. Sagiroglu and D. Sinanc, "Big data: A review," in *Proc. Int. Conf. Collaboration Technol. Syst.*, 2013, pp. 42–47.
[68] E. W. See-To and E. W. Ngai, "Customer reviews for demand distribution and sales nowcasting: A big data approach," *Ann. Operations Res.*, vol. 270, no. 1-2, pp. 415–431, 2018.
[69] B. Shen, C. Dong, and S. Minner, "Combating copycats in the supply chain with permissioned blockchain technology," *Prod. Operations Manage.*, to be published, doi: 10.1111/poms.13456.
[70] B. Shen, X. Xu, and Q. Yuan, "Selling secondhand products through an online platform with blockchain," *Transp. Res. Part E: Logistics Transp. Rev.*, vol. 142, 2020, Art. no. 102066.
[71] J. Shore, J. Baek, and C. Dellarocas, "Network structure and patterns of information diversity on twitter," *MIS Quart.*, vol. 42, no. 3, pp. 849–872, 2018.
[72] N. Siggelkow, "Persuasion with case studies," *Acad. Manage. J.*, vol. 50, no. 1, pp. 20–24, 2007.
[73] D. D. Sokol and M. Van Alstyne, "The rising risk of platform regulation," *MIT Sloan Manage. Rev.*, vol. 62, no. 2, pp. 6A–10A, 2021.
[74] L. Soltanisehat, R. Alizadeh, H. Hao, and K.-K. R. Choo, "Technical, temporal, and spatial research challenges and opportunities in blockchain-based healthcare: A systematic literature review," *IEEE Trans. Eng. Manage.*, to be published, doi: 10.1109/TEM.2020.3013507.
[75] J. Sun, W. Xu, J. Ma, and J. Sun, "Leverage RAF to find domain experts on research social network services: A big data analytics methodology with mapreduce framework," *Int. J. Prod. Econ.*, vol. 165, pp. 185–193, 2015.
[76] L. Sun, G. Hua, T. C. E. Cheng, and Y. Wang, "How to price 3D-printed products? Pricing strategy for 3D printing platforms," *Int. J. Prod. Econ.*, vol. 226, no. 10, 2020, Art. no. 107600.
[77] S. Tiwari, H. M. Wee, and Y. Daryanto, "Big data analytics in supply chain management between 2010 and 2016: Insights to industries," *Comput. Ind. Eng.*, vol. 115, pp. 319–330, 2018.
[78] G. Tsoukalas and B. H. Falk, "Token-weighted crowdsourcing," *Manage. Sci.*, vol. 66, no. 9, pp. 3843–3859, 2020.
[79] A. Vatankhah Barenji, Z. Li, W. Wang, G. Q. Huang, and D. A. Guerra-Zubiaga, "Blockchain-based ubiquitous manufacturing: A secure and reliable cyber-physical system," *Int. J. Prod. Res.*, vol. 58, no. 7, pp. 2200–2221, 2020.
[80] N. Vemprala, C. Liu, and K.-K. R. Choo, "From puzzles to portraits: Enhancing situation awareness during natural disasters using a design science approach," *Decis. Sci.*, to be published, doi: 10.1111/deci.12527.
[81] Y. Wang, Y. Lin, R. Y. Zhong, and X. Xu, "IoT-enabled cloud-based additive manufacturing platform to support rapid product development," *Int. J. Prod. Res.*, vol. 57, no. 12, pp. 3975–3991, 2019.
[82] Z. Wang, Z. Zheng, W. Jiang, and S. Tang, "Blockchain-enabled data sharing in supply chains: Model, operationalization and tutorial," *Prod. Operations Manage.*, vol. 30, no. 7, pp. 1965–1985, 2021.
[83] X. Wen and T. Siqin, "How do product quality uncertainties affect the sharing economy platforms with risk considerations? A mean-variance analysis," *Int. J. Prod. Econ.*, vol. 224, 2020, Art. no. 107544.
[84] J. Wright, "One-sided logic in two-sided markets," *Rev. Netw. Econ.*, vol. 3, no. 1, 2004, Art. no. 29.
[85] P. Wu, F. Chu, N. Saidani, H. Chen, and W. Zhou, "IoT-based location and quality decision-making in emerging shared parking facilities with competition," *Decis. Support Syst.*, vol. 134, 2020, Art. no. 113301.
[86] X. Xu, T. Siqin, S. H. Chung, and T. M. Choi, "Seeking survivals under COVID-19: The WhatsApp platform's shopping service operations," *Decis. Sci.*, to be published, doi: 10.1111/deci.12552.
[87] A. Yazdinejad, R. M. Parizi, A. Dehghantanha, and K.-K. R. Choo, "Blockchain-enabled authentication handover with efficient privacy protection in SDN-based 5G networks," *IEEE Trans. Netw. Sci. Eng.*, vol. 8, no. 2, pp. 1120–1132, Apr./Jun. 2021.
[88] L.-Y. Yeh, P. J. Lu, S.-H. Huang, and J.-L. Huang, "SOChain: A privacy-preserving DDoS data exchange service over SOC consortium blockchain," *IEEE Trans. Eng. Manage.*, vol. 67, no. 4, pp. 1487–1500, Nov. 2020.
[89] R. K. Yin, "Case study research: Design and methods, applied social research," in *Methods Series*. Thousand Oaks, NY, USA: Sage, 1994.
[90] Y. Yu, G. Huang, and X. Guo, "Financing strategy analysis for a multi-sided platform with blockchain technology," *Int. J. Prod. Res.*, vol. 59, no. 15, pp. 1–20, 2020.
[91] H. Yuan, W. Xu, Q. Li, and R. Lau, "Topic sentiment mining for sales performance prediction in e-commerce," *Ann. Operations Res.*, vol. 270, no. 1-2, pp. 553–576, 2018.
[92] G. Zanella, C. Z. Liu, and K. K. R. Choo, "Understanding the trends in blockchain domain through an unsupervised systematic patent analysis," *IEEE Trans. Eng. Manage.*, to be published, doi: 10.1109/TEM.2021.3074310.
[93] L. Zhang, X. Chu, and D. Xue, "Identification of the to-be-improved product features based on online reviews for product redesign," *Int. J. Prod. Res.*, vol. 57, no. 8, pp. 2464–2479, 2019.
[94] R. Y. Zhong, X. Xu, E. Klotz, and S. T. Newman, "Intelligent manufacturing in the context of industry 4.0: A review," *Engineering*, vol. 3, no. 5, pp. 616–630, 2017.
[95] Z. Zhou and X. Wan, "Is mobile digital freight matching platform a disruptive technology to logistics incumbents," in *Production and Operations Management*, Ipswich, MA, USA: EBSCO, 2021.
[96] M. Zihayat, A. Ayanso, X. Zhao, H. Davoudi, and A. An, "A utility-based news recommendation system," *Decis. Support Syst.*, vol. 117, pp. 14–27, 2019.