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The Evolutionary Trends in Production and Operations Management

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Abstract
Accelerated by the intensifying globalization and the relentless advancement of technological revolutions, production and operations management (POM), a vital pillar of corporate competitiveness, is undergoing unprecedented transformations. This paper primarily focuses on four pivotal domains shaping the current and impending trends in POM: smart manufacturing, sustainability, and green production practices, flexibility in responding to market dynamics, and the synchronization of global operations with supply chain partnerships. By delving into the underlying drivers of these trends, the analysis intends to furnish businesses with insightful guidance and practical lessons for their operational strategies. Furthermore, the discourse extends to explore prospective applications of future POM within the realms of global operational strategies, healthcare operations management, and its potential influence on formulating public policies. This comprehensive perspective not only underscores the evolving nature of POM but also underscores its expanding significance across diverse sectors, emphasizing the need for adaptive and forward-thinking approaches in managing production and operational processes.

Keywords: *Production and Operations Management; Supply Chain Optimization; Globalization Dynamics; Sustainability Practices; and Operational Flexibility.*

1. INTRODUCTION

Manufacturing operations management is the management of the design, operation, and maintenance of manufacturing operations systems, which includes managing all aspects of the production process within an organization, such as planning, organizing, and controlling manufacturing operations activities. Production operations management is one of the core pillars of business success, and its importance to business operations is reflected in several dimensions. For example, in the agricultural sector, Patrick et al. (1985) found that agricultural producers consider a wide range of variability in their operations, highlighting the importance of understanding and managing production risks [1]. Similarly, El-Osta et al. (2000) demonstrated that the adoption of technology had a significant impact on the production performance of dairy firms, with the best-performing farms having much lower economic costs compared to low-performing farms, reflecting the efficacy of technological interventions in production activities in the dairy production process [2]. In the area of small firms, Cagliano et al. (2001) explored international differences between countries in terms of production operations management practices and performance, emphasizing the need for effective production operations management strategies in small firms [3]. In addition, Schoenherr et al. (2012) revisited and extended the theory of production capacity, emphasizing the importance of aligning capabilities and priorities to improve the performance of production operations [4]. The importance of production operations management is further emphasized in the literature by Slack et al. (2004), who discuss the historical development of operations management and the need for a research focus in this area [5]. In addition, Schoonenberg et al. (2015) developed a dynamic production model for energy management in industrial systems, demonstrating the application of advanced technologies to optimize energy consumption in the production process [6]. Overall, effective production operations management is manifested in a variety of industries ranging from agriculture to industrial systems, where understanding risks, adopting technologies, aligning capabilities and priorities, and optimizing energy consumption are all key aspects of ensuring the success and sustainability of production operations.

Manufacturing operations management has evolved from the traditional shift from mass production to lean manufacturing and now to smart manufacturing. Lowe (1993) explored the changing role of the production supervisor in the automotive industry, highlighting the emergence of lean manufacturing in

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companies such as Nissan UK and Mazda Flat Rock plant [7].Burcher et al. (1996) proposed a methodology that help traditional repetitive batch manufacturers transition to lean production, emphasizing continuous improvement and world-class manufacturing [8]. Dankbaar (1997) compared lean production to socio-technical systems design (STSD) and traditional Fordist mass production, stating that lean production requires continuous improvement and innovation [9]. Spithoven (2001) discussed the impact of lean production on employees, noting that it is demanding and can lead to increased stress compared to traditional production methods [10]. Holweg (2008) reviewed the evolution of competition in the automotive industry, highlighting the shift from cost leadership to mass customization as the current competitive frontier [11]. Arnheiter et al. (2008) drew on automotive market practices of foreign firms, emphasized the importance of questioning assumptions, and focusing on root causes in managerial decision-making [12]. Recent research has focused on intelligent production technologies such as CPPS intralogistics assessment enabling technology[13]and intelligent service scheduling decision-making technology with artificial intelligence [14]. So what is the development trend of production operation management in the future in the face of globalization, technological innovation, and sustainable development needs? And how should enterprises put forward corresponding production operation management countermeasures in response to the needs of the times?

2. Growing Trend

As a key field to improve the efficiency and competitiveness of enterprises, production operation management was born along with production activities, and the technological changes and production method innovations brought about by many industrial revolutions in history have contributed to the continuous progress of production operation management methods [15]. In modern society, facing the requirements of globalization, technological innovation, and sustainable development, production operation management should follow the trend of the times, and renew the vitality of the times in the application of various fields.

2.1 Intelligent Manufacturing

In today's society, with the rapid development of automation technology, information and communications technology (ICT), Internet technology, and artificial intelligence technology, the global manufacturing industry is moving from automation to intelligence [16]. Currently, countries around the world all regard intelligent manufacturing as a key way to revitalize the manufacturing industry [17], such as Germany in 2011 to implement the "Industry 4.0" development strategy, the United States to implement the "Advanced Manufacturing Partnership Program" and "U.S. Advanced Manufacturing Leadership Strategy", as well as Japan for many years to release the "White Paper on Manufacturing" can reflect this consensus. For China, it is a crucial task to utilize smart manufacturing to promote the transformation and upgrading of the manufacturing industry, improve efficiency and quality, and realize the transformation from a large scale to a strong strength. The Made in China 2025 strategy emphasizes the promotion of smart manufacturing based on the deep integration of new-generation information and communication technologies (ICT) with manufacturing, and seeks to accomplish a fundamental transformation of manufacturing from quantity to quality.

Intelligent manufacturing is a broad manufacturing concept aimed at upgrading production processes and optimizing the flow of goods through the close integration of cutting-edge information technology and manufacturing processes. As a key path for the integration of digital and physical industries, it plays a crucial role in revitalizing the country's manufacturing level and is a key driver of industrial growth. Under the framework of the fourth industrial revolution, smart manufacturing technology has profoundly transformed the process of products from design, manufacturing, to management and integration. With the help of intelligent sensing, adaptive decision-making systems, new materials, high-end equipment, and data analytics tools, it can strengthen every aspect of the product life cycle [18], effectively improving production efficiency, enhancing product quality, and upgrading the service standard.

The core of smart manufacturing is the Intelligent Manufacturing System (IMS), which is the key to transforming the traditional manufacturing system into a smarter model, capable of leapfrogging the production system to a new stage through the introduction of innovative models and technological tools. In the context of Industry 4.0, IMS utilizes Service Oriented Architecture (SOA) to build a human-machine collaborative advanced manufacturing ecosystem by providing collaborative, customizable, flexible, and easy-to-reconfigure services to users via an Internet platform [19]. The system pursues seamless integration between manufacturing processes to optimize the integration of organization, management, and technology application, and the cyber-physical factory of Festo Didactic is a typical example, which, as a part of Germany's "Industry 4.0" strategy, provides training and qualification for large enterprises and educational institutions, demonstrating the application of IMS in practice. It demonstrates the efficient operation and educational value of IMS in practice.

Artificial intelligence plays a key role in the IMS, significantly reducing the need for human intervention by giving the system the ability to learn, reason, and act. For example, the deployment of materials and production resources can be automated, and production activities and operations can be supervised in real-time, all thanks to the application of AI [20]. In the future, autonomous sensing, intelligent networking, intelligent learning and analytics, and smart decision-making will become a reality. Specifically, intelligent scheduling solutions will rely on AI technology and complex problem-solving algorithms to schedule tasks and conveniently serve more users in the form of cloud-based services [21].

2.2 Sustainability And Green Production

By 2050, the global population is expected to exceed 9 billion, with a concomitant dramatic increase in demand for food,

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water, basic goods, and services such as transportation and health care. To support this demand, production systems are projected to need to produce about 140 billion tons of minerals, ores, fossil fuels, and biomass annually, which is about three times the current consumption. At that point, global food production alone would need to increase by 50% [22]. In addition, commodities are not managed effectively in the post-production phase. For example, it is predicted that by 2030, global food loss and waste will reach 2.1 billion tons, equivalent to $15 trillion [23]. This means that about one-third of food is wasted and about 900 million more people will be hungry, a phenomenon that is not justified in any case.

Therefore, in modern society, sustainability and green manufacturing have become an important trend that cannot be ignored in the management of production operations, and many researchers in the academic world have begun to focus on the methods of green manufacturing implementation in different fields. Liu et al. (2019) emphasized the importance of advanced scientific analytical methods for assessing the sustainability of production operations in order to support effective decision-making [24]. Pang et al. (2019) focus on automation in green manufacturing, emphasizing the role of this approach in achieving sustainability and multiple life cycles [25]. Corscadden et al. (2014) discuss material selection trade-offs in manufacturing, presenting a case study on the sustainable alternative use of wool insulation as a renewable resource as a way of applying the concepts of sustainability and green manufacturing to actual production operations management [26]. Yan et al. (2016) explored green parts sourcing collaboration in the high-tech industry with a view to improving supply chain management from a systemic perspective to make its future development more sustainable [27]. Helleno et al. (2017) proposed a methodology integrating sustainability metrics and lean manufacturing for assessing Brazilian industry's production manufacturing processes [28]. Zhou et al. (2022) addressed the limitations of production processes in industry in terms of decision-making, operations, and efficiency, focusing on sustainability and optimized manufacturing through smart sensing, collaborative decision-making, and life cycle assessment [29]. Afzal et al. (2023) investigated the impact of green human resource management (GHRM) practices on the performance of production operations management with green innovation and environmental strategies mediating this relationship [30]. Qureshi et al. (2023) also discussed the relationship between SMEs' use of Industry 4.0 followed by sustainable operations and operational excellence. The study showed that if SMEs adopt Industry 4.0 practices and use advanced robotics to minimize human intervention, as well as the use of intelligent logistics that respond to changes in production capacity, virtual reality, and dynamic simulation technologies, then SMEs can significantly achieve sustainability in their manufacturing operations [31].

In summary, these studies not only demonstrate the integration of theory and practice but also provide manufacturing operations managers with a rich toolbox of strategies and tools in order to help them achieve the dual goals of economic efficiency and environmental protection in a rapidly changing business environment. In the future, with the continuous advancement of technology and higher social expectations for sustainability, the green transformation of production operations management will be a major trend, which will require companies to continue to innovate and deepen interdisciplinary cooperation in order to meet the challenges of global sustainable development.

2.3 Flexibility And Responsiveness To Market Changes

Flexibility in the management of production operations requires firms to focus not only on the optimization of internal processes but also on the ability to adapt quickly to the external environment. Heijnen et al. (2006) proposed a decision support framework aimed at the continuous improvement of batch operations in factories, emphasizing the importance of linking operational activities to plant goals. In the field of energy flexibility measures in industrial systems [32], Tristán et al. (2020) proposed a methodology to systematically identify and characterize available energy flexibility measures to optimize energy-related production costs and support the transition to renewable energy sources [33]. In addition, Xu et al. (2019) estimated the economic value of flexibility in the electricity market for a region, demonstrating the importance of leveraging flexibility to maximize economic returns [34].Sharifzadeh et al. (2015) developed a mixed-integer linear program to determine optimal supply chain design and operations under uncertainty, highlighting the need for rigorous process modeling and economic analysis [35]. Kristoffersen et al. (2020) argued that flexibility is also needed in the manufacturing of personalized products to accommodate the wide variety of changes that occur at the process level at the production site [36]. Cotteleer et al. (2014) found that process flexibility can be achieved by utilizing a production line with 3D printers that can be used to produce a single product [37]. In other words, depending on the equipment or resources available, a manufacturer has the flexibility to choose the best process to produce a product. For example, General Aviation used to produce fuel nozzles by assembling 20 parts. Now, they produce them as a single unit using additive manufacturing techniques.

Strategic flexibility refers to the ability to respond in a timely manner to changes in the competitive marketplace and the ability to respond to changes in the environment in an appropriate manner [38].Sanchez R (1995) found that there have been many studies on strategic flexibility and that early work on strategic flexibility emphasized responsiveness, the need to identify characteristics and acquire appropriate resources in response to the changing environment, and then to develop an appropriate plan for its implementation [39]. Strategic flexibility also requires firms to develop strategic diversity and select appropriate strategies that best fit the current environment [40]. In addition, internal or external environmental changes can also enable a timely response by coordinating flexible resources connected to a cloud-based network. Barz et al. (2016), for example, proposed in their study a methodology for solving the problem of internal or

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external uncertainty in semiconductor production using flexible strategies [41]. They allowed the capacity of each processing equipment to be shared, making the factory more flexible. That is, generally a product is produced in one factory, but if the capacity is insufficient due to various uncertainties, it can be produced in another factory registered in the network.

2.4 Globalization And Supply Chain Synergies

In the management of production operations, globalization means that enterprises can optimize their production layout, reduce costs, and improve competitiveness by using global resources, including labour, raw materials, technology, capital, and markets. Globalized operations allow enterprises to choose production bases based on the comparative advantages of each location, close to the origin of raw materials or consumer markets, to maximize production efficiency. Supply chain collaboration refers to the process of information sharing, process integration, and joint decision-making among all participants in the supply chain (including suppliers, producers, distributors, retailers, and final consumers) to improve overall efficiency and responsiveness. In other words, globalization can provide enterprises with markets, resources, and production opportunities across national boundaries, prompting supply chains to become more extended and complex. This expansion of globalization requires enterprises to manage their internal supply chains more efficiently and flexibly, thus promoting the development of supply chain collaboration. Supply chain collaboration, as a strong support for the globalization strategy of enterprises, is a top priority for the future development of enterprises.

In modern times, collaborative manufacturing is considered a new business model [42]. If the production capacity of a particular process in a factory is insufficient, the product can be produced by sharing processes and machines and utilizing the production capacity of other factories in the network. Seok et al. (2014) found that the available resources in the supply chain network can be used efficiently and the capacity utilization of the factories in the network can be maximized [43]. Chan et al. (2009) in their study emphasized that cooperation within the supply chain through information sharing has a significant impact on supply chain performance [44]. In recent years, with the introduction of new technologies and extensive connectivity, the amount and speed of information generated in supply chains have become more diverse and faster than ever before. Product design, production, and product tracking information is collected in a variety of ways, including RFID and the Internet of Things (IoT), and shared in the cloud. Jun et al. (2011) found in their study that cloud systems monitor and store information generated in the supply chain to provide visibility and enable end-to-end collaborative sharing through information [45]. Collaborative flexibility means that supply chain participants can exchange feedback with each other and work together to deliver customized products. It focuses on integrating design, process planning, production planning, and logistics through information sharing, while supply chain agility focuses on integrating the supply phase through sharing of available capabilities. Petrick et al. (2013) argued that in traditional manufacturing environments, the roles and responsibilities of the designer and the manufacturer are clearly differentiated but in the newer environments, this distinction becomes unclear [46]. In smart supply chains, participants can collaborate from design to delivery; it extends the scope of collaboration compared to traditional methods, for example, by using parallel engineering during the design phase, even during production, the designer can request changes in the manufacturing process based on the availability of the equipment, and the manufacturer can request changes in the product design. Even customers who do not know how to draw CAD models or produce products can request production based on purchased CAD files.

3. Future Prospects

3.1 Global Operations Strategy

Over the past few decades, supply chains have become fragmented and dispersed across the globe. Prior literature has examined the factors that influence an organization's sourcing decisions to other countries. Among the many factors, product cost (including production, transportation, and inventory holding costs) [47], the decision to seek wider markets [48], tax incentives [49], and access to raw materials and technology [50] are among those that have been mentioned in the literature. While there are various advantages of global sourcing including lower prices, higher quality, access to advanced technology, and shorter development time, there are also some associated risks. Global sourcing is associated with economic challenges, political instability, and higher uncertainty, exposing supply chains to higher risks.

3.2 Healthcare Operations Management

The use of electronic health records (EHRs) has led to the aggregation of large amounts of data that can be used by healthcare providers and insurers to make relevant decisions. While EHRs are allowed to share information with other organizations, the aim of improving coordination between different entities in the healthcare supply chain has fostered the emergence of health information exchanges (HIEs).HIEs are often powered by cloud storage and computing technologies to process large amounts of high-dimensional data. Janakiraman et al. (2022) argue that it allows patient information to be transferred from one supply entity to another electronic transfer, which has been shown to improve the quality and efficiency of care [51]. In addition to relying on cloud technologies to collect and manage data, healthcare providers are turning to different Industry 4.0 and Industry 5.0 technologies, such as the Internet of Things and Artificial Intelligence, to collect data to improve patient care and provide telemedicine and virtual care.

3.3 Public Policy

In response to the increase in the number of cybersecurity-related incidents, some governments have taken (or are taking) actions to minimize the likelihood of cyberattacks and mitigate the consequences. For example, the U.S. government's Department of Defense actively identifies "high-risk" supply chain sources and creates a do-not-buy list

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of software products to minimize the risk of supply chain disruptions [52], and has banned the use of Kaspersky by the Pentagon, the General Services Administration (GSA), and the National Aeronautics and Space Administration (NASA). The Pentagon, the General Services Administration, and the National Aeronautics and Space Administration (NASA) are also prohibited from using Kaspersky software [53].

While previous research on production and operations management has examined the effects of policies of various industry regulators (e.g., the Food and Drug Administration), Joglekar et al. (2016) argued that future research on production and operations management needs to not only examine the effects of policies on business operations but also understand the two-way interactions between various public policies and business decisions [54]. Given the number of cybersecurity incidents and the severe consequences of these incidents, it is critical to develop strong policies to reduce the number of incidents and improve recovery from cyberattacks, and it is also important to understand the interactions between policies and business operations.

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