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Review

A Review of Game Theory Models to Support Production Planning, Scheduling, Cloud Manufacturing and Sustainable Production Systems

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Abstract: Cyber-physical systems, cloud computing, the Internet of Things, and big data play significant roles in shaping digital and automated landscape manufacturing. However, to fully realize the potential of these technologies and achieve tangible benefits, such as reduced manufacturing lead times, improved product quality, and enhanced organizational performance, new decision support models need development. Game theory offers a promising approach to address multi-objective problems and streamline decision-making processes, thereby reducing computational time. This paper aims to provide a comprehensive and up-to-date systematic review of the literature on the application of game theory models in various areas of digital manufacturing, including production and capacity planning, scheduling, sustainable production systems, and cloud manufacturing. This review identifies key research themes that have been explored and examines the main research gaps that exist within these domains. Furthermore, this paper outlines potential future research directions to inspire both researchers and practitioners to further explore and develop game theory models that can effectively support the digital transformation of manufacturing systems.

Keywords: game theory; manufacturing systems; cooperation; decision making; network

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1. Introduction

The digital transformation, driven by the principles of Industry 4.0, offers unprecedented opportunities for industrial companies to revolutionize efficiency and customer satisfaction [1–3]. This evolution hinges on interoperable physical and cyber systems, decentralization, and real-time data analytics. These advancements empower companies to establish geographically dispersed multi-factory supply chains, enhancing flexibility while reducing labor and logistics costs [4]. Companies achieve this through the strategic distribution of production capacity or by forging collaborative multi-entity supply chains. Industrial applications of multi-site production planning and scheduling abound, spanning semiconductor manufacturing [5], automotive [6], pharmaceutical [7], and TFT-LCD [8]. However, this paradigm shift introduces complexity into planning and scheduling models, requiring solutions that can be found quickly and efficiently. Metaheuristic approaches have shown promise [4], and game theory, in particular, offers a powerful analytical tool that is well-suited to address interactions among multiple decision makers engaged in multi-objective optimization. Game theory is a branch of mathematics that studies strategic decision making in situations where multiple agents interact with each other. It provides a framework for analyzing and predicting the behavior of players in competitive and cooperative scenarios. Game theory is a powerful tool for analyzing strategic decision making in various contexts. By understanding its key elements, types, applications, and benefits, we can gain valuable insights into complex interactions and design effective strategies for different scenarios. Game-theory-based approaches have been successfully applied to solve various complex engineering problems, including power systems, collaborative product design, and production planning, enhancing solving efficiency [9]. A notable advantage of game theory is that it solves distributed algorithms in less time and with less computations compared to heuristic-based approaches [10].

Driven by the significance of game theory for production planning and scheduling in cooperation among multi-factory and cyber systems, there is a growing interest in leveraging its principles to optimize manufacturing processes. As manufacturing systems become increasingly complex and interconnected, game theory offers a powerful framework to model strategic interactions and decision making among various entities involved in production activities. This includes manufacturers, suppliers, distributors, and even autonomous cyber systems operating in smart factories. By applying game theory, researchers and practitioners aim to enhance efficiency, resource utilization, and overall performance in modern manufacturing environments characterized by interconnectedness and interdependence. This research proposes an overview of the recent applications of game theory to answer the following questions: What are the current research trends on the use of game theory for production planning and scheduling? What, then, are the existing research gaps and what are the potential contributions for future research? The structure of this paper is organized as follows: Section 2 outlines the review methodology. Section 3 describes the literature review following the areas of production planning problems, scheduling, sustainable production systems and smart and cloud manufacturing. Section 4 discusses the key findings of the literature review and identifies the limits. Section 5 concludes with a summary and a discussion of future research needs.

2. Research Methodology

The research methodology follows the guidelines proposed by Durach et al. [11]: (1) defining the research question, (2) determining the required characteristics of primary studies, (3) retrieving a sample of potentially relevant literature, (4) selecting the pertinent literature, (5) synthesizing the literature, and (6) reporting the results.

2.1. Question Formulation and Keywords

The first stage of this research involves defining the research questions. The main question focuses on understanding the current state of game theory models and their relevance in addressing the evolving needs of Industry 4.0. The research will then delve deeper into exploring how game theory models can facilitate various aspects, such as production and capacity planning, scheduling, sustainable production systems, and cloud manufacturing. Production planning is the process of organizing and coordinating resources to ensure efficient manufacturing of products. It involves determining what to make, how much to make, and when to make it to meet customer demand while minimizing costs. Production scheduling is the process of sequencing and timing production activities to optimize efficiency and meet customer demand. It involves determining the start and end dates for each task, as well as the resources needed to complete each task. Sustainable production systems refer to manufacturing processes and practices that are designed and operated in a manner that minimizes negative environmental impacts, conserves resources, promotes social equity, and ensures long-term economic viability. Cloud manufacturing is the use of cloud computing technologies to deliver manufacturing services on demand. It is a new paradigm that enables manufacturers to access and use manufacturing resources, such as software, hardware, and data, from a cloud-based platform. Then, it is necessary to define the keywords involved in this study. The main keywords are the following: “Game Theory” and “distributed production planning”, “industry 4.0”, “cloud manufacturing”, “scheduling”, “sustainable manufacturing”, “energy saving”, “energy reduction”, “cooperative game”, “non-cooperative game”,” industry 4.0”, and “smart manufacturing”.

2.2. Inclusion/Exclusion Criteria

To focus the study and limit the literature search, a set of criteria was developed to identify the most relevant articles. These criteria are presented in Table 1.

Table 1. Inclusion and exclusion criteria used to select papers.

	Criteria	Justification
Inclusion	Papers published between 2013 and the first half of 2023	Most recent papers that focus on Industry 4.0
	Publications in peer-reviewed journals and conference papers	Peer-reviewed journals assures the quality of the research discussed
Exclusion	Production planning models not related to Industry 4.0	The purpose of this research is approaches for Industry 4.0 context.
	Studies in a language other than English	This assures that this research can be read by more researchers.

2.3. Database for Relevant Literature

A comprehensive search of three prominent academic databases—Google Scholar, Web of Science, and Scopus—was conducted to identify relevant articles. The initial search utilized predefined keywords to generate a preliminary set of articles. To refine this set further, a strict inclusion/exclusion criteria filter was applied. Additionally, only articles published in conferences indexed by Scopus or Web of Science were included to ensure a high level of quality.

2.4. Selecting the Pertinent Literature

To broaden the article selection process, the references of the initial set of evaluated articles were examined. This allowed for the identification of key authors who have made significant contributions to the main themes of this review. By analyzing their work, a secondary search was conducted, which enriched and diversified the scope of the reviewed literature.

2.5. Synthesizing the Literature

Following the identification of relevant articles, the next phase involved literature synthesis. Aligned with the research questions established earlier, the articles were categorized based on the specific issues they addressed and the research methodologies employed. The primary areas of focus included production and capacity planning, scheduling, sustainable production systems, and smart and cloud manufacturing.

2.6. Reporting the Results

The following sections analyze the selected literature, focusing on production and capacity planning, scheduling, sustainable production systems, and smart and cloud manufacturing. This analysis aims to identify current trends, research gaps within each area, and explore promising future research directions. The review encompasses 35 papers, selected from an initial pool of over 100 articles. The majority of the articles were sourced from the Scopus index, with only two articles originating from conference publications. The selection process also involved examining references, with an emphasis on the number of citations that each article received. Notably, the reference analysis did not identify specific authors as key contributors to this field.

3. Literature Review

The literature review is structured based on the classification outlined in the paper, which categorizes the research into distinct groups: production planning problems, scheduling, sustainable production systems, and cloud manufacturing. This approach allows for a systematic examination of the existing body of literature, enabling a comprehensive analysis of each specific area, facilitating the identification of key research themes, trends, and gaps within these domains.

3.1. Production and Capacity Planning

This section addresses the challenges of production and capacity planning in distributed geographic networks. These networks enable enterprises to pool capacity, services, and technology, enhancing efficiency, responsiveness, and competitiveness. By leveraging this network, enterprises can effectively respond to unforeseen events such as demand fluctuations, machine breakdowns, rush orders, and supplier delays.

Argoneto and Renna [12] proposed a model to support capacity sharing for a set of independent firms that were geographically distributed, combining their resources and predicting demand to improve production and cost efficiency. The partners of the network are independent and share partial information. A multi-agent architecture has been developed to support cooperation activities in this context. The coordination model uses the Gale–Shapley algorithm to find a stable matching among plants in the network, including the information that each partner decides to share using the preferences function.

Krenczyk and Olender [13] studied the problem of production planning in a virtual manufacturing network with geographically distributed manufacturers. The objectives were to minimize cycle time and production costs. The proposed approach uses a multi-agent system that solves the problem with a non-cooperative game. The selection of alternative routes for a set of production orders is modeled as a non-cooperative game f-player non-zero-sum game with complete information. The model proposed is a framework of a potential application but any numerical test is provided.

Yin et al. [14] proposed a non-cooperative model to allocate production to multi-suppliers from one manufacturer. The model considers quality and demand variations. The proposed approach is a non-cooperative game based on the Stackelberg equilibrium, where the manufacturer is regarded as a leader and the suppliers as followers. As argued by the authors, the model needs to be studied on a larger scale to evaluate its application in real industrial cases.

Olender and Krenczyk [15] proposed the use of a game theory approach to support the production planning problem in a virtual manufacturing network. The objectives were the minimization of production and transport costs using a non-cooperative game. A very limited numerical case was discussed.

Hafezalkotob et al. [16] addressed the approach of coalitions of production plants for cooperative production planning problems. They proposed several methods of cooperative game theory, including the Shapley value. The numerical results highlight how cooperation ensures the satisfaction of production plants, reducing total costs.

Bigdeli et al. [17] proposed a game theory model to support a production planning problem with fuzzy variables. Duality theory in the single-objective and weighted sum methods in multi-objective games is proposed to obtain the payoffs of the players.

Renna [18] studied capacity and resource allocation in flexible production networks. The objective is to obtain a trade-off between the costs and flexibility of the network to satisfy the customer demand. A dynamic allocation of the flexibility is proposed based on the game theory approach using the Gale–Shapley algorithm. The proposed model allows the performance of the network to improve compared to the long-chain approaches proposed in the literature.

Nishizaki et al. [19] addressed two-stage stochastic linear production planning with partial cooperation, involving resource pooling, technology transfer, and product transshipment. Manufacturers determine production levels individually in the first stage, and then collaborate to produce products using pooled resources in the second stage. Additional profits from cooperative game theory are distributed among all manufacturers. We developed a method to maximize total profits by finding a Nash equilibrium point valuated by numerical examples.

Table 2 summarizes the primary contributions of recent research on production and capacity planning, outlining key characteristics such as the addressed problem (capacity or production planning), the development of multi-agent System (MAS) architecture to support activities, the level of cooperation (non-cooperative or coalition), and the specific algorithm proposed (Gale–Shapley or Shapley Value). Notably, recent studies show that while one study utilized a coalition approach, the majority focused on non-cooperative models. Additionally, capacity planning has been addressed to a lesser extent compared to production planning.

Table 2. Production and capacity planning works.

	Capacity	Production Planning	MAS	Non-Cooperative	Coalition	Gale–Shapley	Shapley Value	Nash
Argoneto and Renna [12]	X		X			X		
Krenczyk and Olender [13]		X	X	X				
Yin et al. [14]		X		X				
Olender and Krenczyk [15]		X		X				
Hafezalkotob et al. [16]		X			X		X	
Bigdeli et al. [17]		X		X				
Renna [18]	X					X		
Nishizaki et al. [19]		X						

3.2. Scheduling

In today's competitive environment, scheduling models need to be highly responsive to real-time events, leveraging the vast amount of data available from Industry 4.0 technologies. However, the abundance of information also brings about increased computational complexity, necessitating more efficient scheduling algorithms to capitalize on this opportunity. Game theory emerges as a promising model to address scheduling challenges with greater efficiency.

Sun et al. [20] studied the flexible job-shop scheduling problem subject to machine breakdown, considering the objectives of robustness and stability. To optimize these two objectives, they modeled the problem as a non-cooperative game and the Nash equilibrium was derived to optimize the two objectives.

Chandrasekaran et al. [21] studied the n-job, m-machine job-shop scheduling problem using a game theory model to find the optimal makespan, mean flow time, and mean tardiness values. The approach proposed is a simplified heuristic derived from game theory tested in a reduced scheduling problem.

Han et al. [22] studied the flow-shop scheduling problem with component altering times, which is a particular problem for sequence-dependent setup times. They developed six rules for the machine assignment of jobs and proposed a Nash equilibrium model to manage these rules. The numerical results show how the game theory model performs better than a model using a genetic algorithm.

Renna [23] proposed a reconfigurable machine scheduling method based on a Gale–Shapley model. The Gale–Shapley model forms a coupled of overloaded and underloaded machines to allocate the modules for the reconfigurable machines. The numerical results of the simulation model show how the game theory model improves all performance measures with a restricted number of machine reconfigurations.

Wang et al. [24] proposed a multi-agent architecture to support real-time scheduling in flexible job-shop systems. A bargaining game model based on the Nash equilibrium was developed to support coordination among the agents of the architecture.

Nie et al. [25] modeled the flexible job-shop scheduling problem as a game theory model where the manufacturer wants to minimize the makespan of all jobs, and the job wants to minimize its tardiness. The game is solved by searching the Nash equilibrium, supported by a genetic algorithm.

Renna et al. [26] studied the dual resource scheduling problem in job-shop manufacturing systems. They proposed a Gale–Shapley model to support worker assignment for dual resource-constrained job-shop problems. The simulation experiments highlight how the Gale–Shapley model leads to better results, particularly when the workers have different efficiency levels.

Atay et al. [27] studied open-shop scheduling problems to minimize the total completion times. They proposed a cooperative TU game and allocate the affected jobs for each alliance to minimize the makespan.

Han et al. [28] modeled the flow-shop scheduling problem with multiple batches as a game model. The method proposed is based on multi-player cooperation and a static game with complete information. The proposed method allows the waiting time to be reduced and improves other performance measures of the flow line.

Wei et al. [29] addressed the multi-objective dynamic flexible job-shop scheduling problem when unforeseen events such as machine breakdown occur. They developed a model that approximates the Nash equilibrium solution to balance Pareto optimality and fairness between the two objectives of production efficiency and stability. The numerical results of several problem sizes are compared to three meta-heuristics proposed in the literature.

Table 3 summarizes the key findings from recent research on scheduling problems in manufacturing systems. The table highlights various characteristics, including the type of manufacturing system studied (flow line, job-shop, and reconfigurable), the game theory approaches employed (cooperative, Nash equilibrium, and Gale–Shapley), the use of multi-agent system (MAS) architecture, and the integration with genetic algorithms.

Table 3. Studies on scheduling.

	Flow Line	Job Shop	RMS	Open Shop	Cooperative Model	Nash Eq.	Gale–Shapley	MAS	Genetic Algorithm
Sun et al. [20]		X				X			
Chandrasekaran et al. [21]		X			X				
Han et al. [22]	X					X			
Renna [23]			X				X		
Wang et al. [24]		X				X		X	
Nie et al. [25]		X				X			X
Renna et al. [26]		X					X		
Atay et al. [27]				X	X				
Han et al. [28]	X				X				
Wei et al. [29]		X			X				

Notably, recent research reveals that only one study has explored reconfigurable manufacturing systems and open-shop scenarios. Additionally, the integration of game theory with other optimization techniques, such as genetic algorithms, has only been proposed in a single article.

3.3. Sustainable Production Systems

In recent years, the growing relevance of climate change, coupled with rising energy costs, has prompted manufacturing systems managers to prioritize energy efficiency and the utilization of renewable energy sources. These factors underscore the increasing significance of sustainable production systems.

Zhang et al. [30] proposed a dynamic game model based on the Nash equilibrium to improve production efficiency further and reduce processing costs, including total energy consumption for flexible job-shop problems. The numerical test highlighted reducing makespan, the total workload of machines, and the total energy consumption compared to genetic algorithm solutions.

Renna [31] developed a model to allocate the power to machines using the Gale–Shapley algorithm. The model exchanges the power from the underloaded to overloaded machines. The simulation results show how the model can improve the performance of a manufacturing system under a constraint power limit.

Wang et al. [32] studied the real-time scheduling problem in a job shop with the application of Internet of Things technology to improve production efficiency and reduce energy consumption. An infinitely repeated game optimization approach is developed, and the numerical results show that game theory can improve results compared to other dynamic scheduling methods.

Schwung et al. [33] presented a multi-agent architecture for a decentralized control design of modular production units. The interactions among the agents are supported by a game theory approach. The numerical tests show promising results for improvements in production efficiency in terms of energy consumption as well as throughput times.

Wang et al. [34] proposed a scheduling model for a flexible job shop in real-time. An evolutionary game-based solver method was proposed to support the scheduling model improving energy efficiency.

Sun et al. [35] proposed a digital twin framework to support process planning and scheduling in job-shop systems. Then, a dynamic game theory was adopted to improve production efficiency and reduce energy consumption. The model considered two sub-games, the process planning sub-game and scheduling sub-game, integrated with the Nash equilibrium solution.

Zhao et al. [36] proposed an optimization method for shared energy storage in micro-grids using negotiation game theory. This establishes a cooperative interaction mechanism between Microgrid Cluster Operator (MGCO) and Shared Energy Storage Operator (SESO), leading to an optimization framework for microgrid clusters. The dynamic leasing of shared energy storage is considered, resulting in a negotiation game-based capacity configuration model for MGCO and SESO, demonstrating a cost reduction for MGCO and revenue increase for SESO.

Table 4 summarizes the key findings from recent research on applying game theory to sustainable production systems. While the majority of studies focus on job-shop systems, only one addresses peak power constraints. Significantly, no studies explored using game theory to optimize the adoption and integration of renewable energy sources within manufacturing systems.

Table 4. Studies on sustainable production systems.

	Job Shop	Nash Equilibrium	Gale–Shapley	MAS	Cooperative Model	Energy	Peak Power
Zhang et al. [30]	X	X				X	
Renna [31]	X		X	X			X
Wang et al. [32]	X				X	X	
Schwung et al. [33]	X			X	X	X	
Wang et al. [34]	X				X	X	
Sun et al. [35]	X	X				X	
Zhao et al. [36]					X	X	

3.4. Cloud Manufacturing

Cloud manufacturing represents an emerging paradigm where distributed resources are encapsulated into cloud services and centrally managed. This network of shared resources enables customers to access on-demand services supporting the entire product lifecycle. The efficiency of cloud manufacturing is heavily dependent on coordination models.

Su et al. [37] studied the problem of manufacturing resource allocation, in which the manufacturing service demander and cloud manufacturing service platform operator are considered gamers. They proposed a non-cooperative game approach to support the problem of resource allocation.

Liu et al. [38] proposed a model of resource and service sharing in cloud manufacturing sharing based on the Gale–Shapley algorithm. The results of the proposed model highlighted that there are always enterprises of the network that perform worse.

Carlucci et al. [39] proposed a coordination model based on a minority game to allocate resources/services among partners of a cloud manufacturing system. The proposed model was tested in a simulation environment compared to a model with complete information among the partners.

Xiaoning et al. [40] investigated three resource-sharing strategies: independently, as an alliance, and by cooperating with a cloud platform operator. The interactions between the operator and suppliers were modeled as a two-stage Stackelberg game that contains a simultaneous sub-game. They found the highest system profit when the suppliers cooperate with the operator.

Xiao et al. [41] proposed a cloud manufacturing multi-task scheduling model based on game theory from a customer perspective. The model is derived from the Nash equilibrium game. The simulation results highlight how the proposed model leads to better results compared to basic biogeography-based optimization algorithms, genetic algorithms, and particle swarm optimization.

Wang et al. [42] studied decentralized decision making in the management of manufacturing service allocation in cloud manufacturing systems. The model is based on an evolutionary game approach able to converge to equilibrium.

Zhang et al. [43] considered a cloud manufacturing system where each manufacturer provides manufacturing resources; when the cloud manufacturing received an order, it coordinated manufacturing resources to satisfy order requirements. To solve the scheduling problem of cloud manufacturing, they proposed a genetic algorithm with the use of the Nash equilibrium for a non-cooperative game model.

Liu et al. [44] studied the application of a cloud manufacturing approach for 3D printing services. They proposed a non-cooperative game model for a 3D printing service scheduling problem. The non-cooperative game is based on Nash equilibrium points supported by a genetic algorithm.

Liu et al. [45] proposed a game-theory-based collaborative scheduling approach for cloud manufacturing (CMfg), addressing dynamics and uncertainties. It optimizes manufacturing and logistic resources efficiently, considering fuzzy uncertain task migration. The model achieves the Nash equilibrium through a decision tree optimization algorithm, enhancing transportation efficiency. Simulation results validate its effectiveness and performance in dynamic CMfg environments.

Koochaksaraei et al. [46] presented a novel approach for cloud service providers (CSPs) to efficiently allocate resources through a barter-based auction market, using evolutionary game theory. CSPs estimate and bid their resources without monetary exchange, fostering cooperation and reducing SLA violations. The simulation results demonstrate improved social welfare and fewer contracts.

Zhang et al. [47] proposed a real-time strategy for a flexible job-shop scheduling problem-based on game theory. The solution and optimization strategy for process tasks using the Nash equilibrium was designed and developed to implement the dynamic optimization model. A case study is presented to demonstrate the efficiency of the proposed strategy and method.

An emerging issue concerns using the circular economy to improve the sustainability of different enterprise sectors, such as manufacturing systems [48], the apparel industry [49], and civil engineering [50].

Tushar [51] provided a recent overview of the literature on cyber–physical systems supported by different game theory models. They argued that multi-agent and game theory are adapted to support cyber–physical systems.

Table 5 summarizes the key findings from recent research on applying game theory to cloud manufacturing systems. Notably, the Nash equilibrium is the dominant approach, with fewer studies exploring alternative methods such as the Gale–Shapley model or minority game models. This suggests potential avenues for future research.

Table 5. Studies on cloud manufacturing systems.

	Resources	Service	Nash Eq.	Gale–Shapley	Cooperative Model	Non Cooperative Model	Minority Game
Su et al. [37]	X					X	
Liu et al. [38]	X	X		X			
Carlucci et al. [39]	X	X					X
Xiaoning et al. [40]	X				X		
Xiao et al. [41]	X		X				
Zhang et al. [45]	X		X				
Wang et al. [42]		X	X				
Zhang et al. [43]	X		X			X	
Liu et al. [44]	X		X				
Liu et al. [45]		X	X		X		
Koochaksaraei et al. [46]		X				X	

4. Main Findings

This section synthesizes the findings from the reviewed literature. Based on this analysis, we will identify research gaps and discuss potential avenues for future research. Table 6 summarizes the distribution of the reviewed papers across different areas in recent years (2014–2023) and in terms of percentages of the total reviewed papers.

Table 6. Summary of the literature review.

	2014–2016	2017–2019	2020–2022	2023	No.	%
Production and capacity planning	4	1	2	1	8	22.86%
Scheduling	3	3	3	1	10	28.57%
Sustainable production systems	-	2	3	2	7	20.00%
Cloud manufacturing	1	4	3	2	10	28.57%
Total	8	10	11	2	35	

The analysis of the reviewed literature reveals that research on production and capacity planning peaked between 2014 and 2016, with a decline in subsequent years. Conversely, the application of game theory approaches to scheduling problems has remained consistent throughout the study period. Interestingly, sustainable production systems and cloud manufacturing have emerged as growing areas of interest, with cloud manufacturing attracting the most recent research efforts. Figure 1 visually depicts this trend, highlighting the surge in research focused on sustainable manufacturing systems and cloud manufacturing in recent years.

4.1. Key Outcomes for Production and Capacity Planning

A critical gap identified in recent production and capacity planning research is the lack of models that facilitate coalition formation among enterprises. Such models could enhance efficiency, responsiveness, and resource sharing, ultimately leading to improved customer satisfaction. Small and Medium Enterprises (SMEs) could leverage these coalitions to compete more effectively on the global stage [52]. However, cooperative game theory models, which are well suited for analyzing coalition formation, have not been extensively explored in this area.

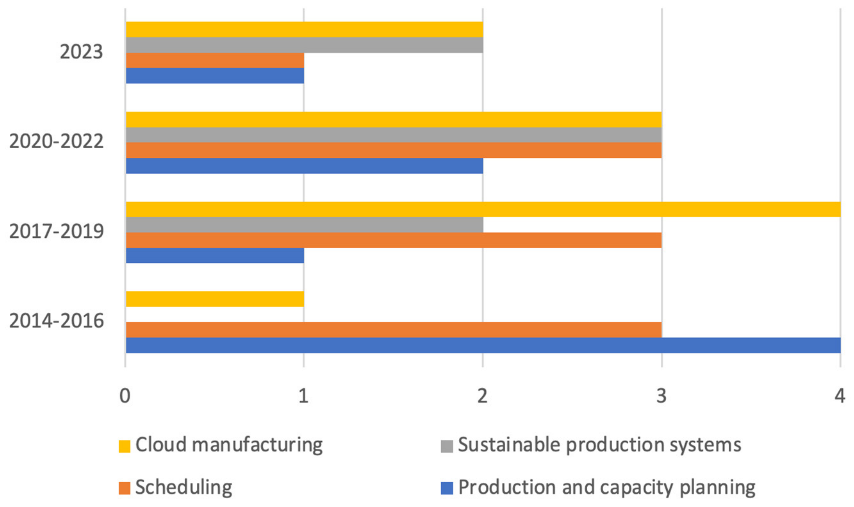

Figure 1. Trend of the literature review.

Another promising avenue for applying cooperative game theory lies in the realm of strategic alliances, often referred to as 'co-opetition' [53]. These alliances unite competing enterprises with complementary capabilities to pursue shared objectives such as expanding market share, improving efficiency, and fostering innovative solutions. By integrating cooperative game theory into the context of capacity and production planning, researchers can develop models that optimize coalition formation and resource sharing among enterprises. This approach holds immense potential for SMEs, allowing them to gain a competitive edge and make meaningful contributions to the global manufacturing landscape.

4.2. Key Outcomes on Scheduling

Recent research on scheduling for manufacturing systems has primarily focused on job shops, with reconfigurable and open-shop systems receiving less attention. However, these under-explored systems offer significant potential for leveraging game theory models to improve decision making and operational efficiency. In particular, reconfigurable manufacturing systems boast a modular and adaptable design, allowing them to swiftly adapt to changing production needs. Game theory models can play a pivotal role in allocating and reconfiguring machines and equipment. By optimizing resource utilization within a limited availability, decision makers can strike a balance between resource allocation and production objectives.

Unlike job-shop systems, open-shop systems accommodate a broader spectrum of process types and job priorities. Game theory models step in to provide efficient solutions while minimizing computational time. By dynamically considering job arrivals and process requirements, game theory guides decision makers in scheduling tasks. The goals? Minimizing idle time, reducing production lead times, and boosting system responsiveness.

From the point of view of integration challenges, there is a critical gap in the existing literature—an underexplored fusion of game theory with other methodologies.

Two promising avenues are as follows: fuzzy logic is renowned for handling imprecise and uncertain information and can effectively complement game theory. Integrating these approaches takes into account the inherent variability and complexities of real-world manufacturing environments. Genetic algorithms are algorithms that search for optimal solutions through evolutionary processes. When combined with game theory, they explore a broader array of scheduling alternatives, ultimately identifying the most efficient paths. In summary, bridging game theory with fuzzy logic and genetic algorithms can pave the way for more robust and adaptable scheduling models, ultimately enhancing decision-making efficiency in manufacturing systems.

Reconfigurable manufacturing systems, with their modular and adaptable designs, can leverage game theory models to optimize resource allocation and the reconfiguration of machines and equipment. This is particularly valuable in scenarios with limited resource availability. By applying game theory, decision makers can make informed choices that balance resource allocation with production objectives, ultimately maximizing overall system efficiency. Open-shop systems, characterized by a wider range of process types and job priorities, present another promising area for applying game theory. In these systems, game theory models can efficiently identify solutions while minimizing computational time. Game theory's strength lies in its ability to account for the dynamic nature of job arrivals and process requirements. This allows it to guide decision makers in real-time task scheduling, minimizing idle time, reducing production lead times, and ultimately enhancing system responsiveness. However, a critical gap exists in the current research—the limited exploration of how game theory can be combined with other methodologies. Fuzzy logic, known for its ability to handle imprecise information, can complement game theory in real-world manufacturing environments where data may be uncertain. Similarly, genetic algorithms, which utilize evolutionary processes to find optimal solutions, can be integrated with game theory to explore a wider range of scheduling options and identify the most efficient paths. By combining these approaches, researchers can develop more robust and adaptable decision models for scheduling problems.

Fuzzy logic, with its ability to handle imprecise and uncertain information, can be integrated with game theory to account for the inherent variability and complexities of real-world manufacturing environments. This integration can improve the robustness and adaptability of scheduling models to changing conditions and disruptions. Genetic algorithms, with their ability to search for optimal solutions through evolutionary processes, can be combined with game theory to explore a wider range of scheduling alternatives and identify the most efficient solutions. This integration can enhance the computational efficiency of scheduling models and lead to more robust and effective scheduling strategies. By fully leveraging the power of game theory and integrating it with complementary methodologies, researchers can address the challenges of scheduling in reconfigurable and open-shop systems, unlocking new avenues for enhancing manufacturing efficiency and productivity.

4.3. Key Outcomes on Sustainable Production Systems

Sustainability has emerged as a key driver in manufacturing, prompting research into sustainable production systems that minimize environmental impact while maintaining economic viability. Recent studies have focused on job-shop manufacturing systems, primarily considering total energy consumption. However, a crucial aspect—the costs associated with peak power constraints—has received less attention. Additionally, the utilization of renewable energy sources has not been extensively explored in recent research. The allocation of demand energy among various renewable energy sources presents a promising research direction that can be effectively addressed using game theory models. By incorporating game theory's principles of strategic decision making, researchers can develop models to optimize the utilization of renewable energy sources while ensuring the overall energy demand is met. This approach holds immense potential for minimizing reliance on conventional energy sources and reducing the environmental footprint of manufacturing operations. Game theory models can capture interdependencies among different renewable energy sources, considering their fluctuating availability, variability in generation patterns, and associated costs. By analyzing these interactions, researchers can identify optimal strategies for scheduling the use of renewable energy sources, ensuring that demand is met while maximizing the utilization of these sustainable resources. Furthermore, incorporating game theory into the optimization of renewable energy utilization can facilitate collaboration among different stakeholders, such as energy providers, manufacturers, and consumers.

By modeling their decision-making processes and aligning their interests, game theory can promote the efficient coordination of renewable energy resources, leading to a more sustainable and resilient energy landscape. By embracing game theory as a tool for optimizing renewable energy utilization in sustainable production systems, researchers can pave the way for a future where manufacturing operations operate in harmony with the environment, reducing their carbon footprint and promoting the transition towards a sustainable future.

4.4. Key Outcomes on Cloud Manufacturing

Cloud manufacturing, a transformative paradigm, has emerged in manufacturing, enabling distributed and collaborative production capabilities. While recent research has primarily investigated the allocation of manufacturing resources and services within cloud manufacturing systems, two crucial aspects demand further investigation: cooperative models and design stage support. Cooperative models are essential for facilitating cooperation among the diverse stakeholders within cloud manufacturing ecosystems, including cloud providers, manufacturers, and customers. Game theory offers a powerful framework for modeling these interactions. By analyzing strategic decision making, game theory can aid in the design of mechanisms that promote efficient cooperation. These mechanisms can optimize resource allocation, maximize utilization of cloud manufacturing capabilities, and align the interests of all parties involved, ultimately contributing to a more sustainable and equitable cloud manufacturing landscape.

Design stage support is critical for reducing the gap between customer requirements and the actual production process in cloud manufacturing. Game theory can be leveraged to develop collaborative design models that facilitate the active participation of customers, designers, and manufacturers. These models enable a participatory design process, empowering customers to express their specific needs and preferences while designers and manufacturers can offer expert guidance, feasibility assessments, and technical expertise.

By incorporating cooperative models and design stage support into cloud manufacturing systems, researchers can pave the way for a more agile, responsive, and customer-centric manufacturing paradigm. This approach empowers customers to actively participate in the design and production of their desired products and services. In turn, manufacturers gain valuable insights, improve customer satisfaction, and potentially unlock new avenues for innovation and competitive advantage.

5. Conclusions

The adoption of new technologies and digitization generate vast amounts of real-time data, which necessitates the adoption of novel organizational and cooperative models. Game theory models can expedite cooperation among independent partners, reducing computational time compared to alternative methodologies.

This review surveys recent research (2014–2023) utilizing game theory models in production and capacity planning, scheduling, sustainable production systems, and cloud manufacturing. The literature review examines the application of game theory models in these areas, identifying key research gaps and proposing future directions.

Coalition models are an important area for study, offering support across various topics. Cooperative game models facilitate collaboration among multi-site or manufacturing resources within the same enterprise, while non-cooperative game models with incomplete information aid independent enterprises in temporary collaborations. Integrating game theory models with other methodologies, such as genetic algorithms, fuzzy logic, and Monte Carlo simulations, can enhance multi-objective solutions and reduce computational complexity for real-time data.

The management and integration of renewable energy sources are a critical area that can benefit from game theory models. Decision support models based on game theory can allocate energy demand among various sources, including solar, wind, and storage options, aiming to minimize total energy consumption, address peak power constraints, and maximize renewable sources.

Future Research Paths

The main key points for future research paths can be summarized as follows.

Future research in manufacturing systems will focus on open-shop and reconfigurable manufacturing systems, which stand to gain significant benefits from game theory models. Advancing these open research areas is essential for expanding knowledge on the use of game theory models and supporting industry and practitioners in transitioning towards decision support systems for new organizational paradigms.

Existing studies on capacity and production planning have neglected the application of cooperative game theory in facilitating coalition formation and resource sharing among enterprises, especially SMEs. Cooperative game theory offers valuable insights for designing and managing strategic alliances to optimize mutual benefits and minimize potential conflicts. It provides a structured framework for analyzing and negotiating resource allocations, fostering collaboration, and enhancing overall operational efficiency.

Research on scheduling has predominantly centered on job shops, overlooking reconfigurable and open-shop systems. Game theory models offer effective solutions for optimizing resource utilization, minimizing idle time, reducing lead times, and enhancing responsiveness in these systems. Integrating game theory with complementary methodologies like fuzzy logic and genetic algorithms can further improve scheduling model efficacy.

While recent research on sustainable production systems has emphasized job-shop systems and total energy consumption, it has often neglected costs related to peak power constraints and the integration of renewable energy sources. Game theory models offer opportunities to optimize the utilization of renewable energy sources, ensuring demand fulfillment while minimizing reliance on conventional energy sources. Moreover, game theory can foster collaboration among stakeholders to efficiently coordinate renewable energy resources.

While research on cloud manufacturing has predominantly centered around resource allocation, there has been limited exploration of cooperative models and design stage support. Cooperative game theory presents an opportunity to develop efficient mechanisms for resource allocation and engage customers in the design and production processes of their desired products and services. Integrating cooperative models and design stage support can enhance the flexibility, responsiveness, and customer centricity of cloud manufacturing.

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