



# Recent trends in distributed production network scheduling problem

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## Abstract

The complex problems in the real world, an increase in competition among producers, the advancements in equipment and manufacturing products, the high cost of factory equipment and, etc., have led to the production structure change from a centralized structure to a decentralized one. In recent years, distributed systems have become increasingly important. So in order to adapt to market competition and to respond quickly to changing market demand, there is a need to study this problem. An important aspect of planning in a distributed environment is decentralized production. In such cases, it becomes more important to consider the problem of distributed scheduling. In this regard, this paper provides a systematic literature review on the multi-factory scheduling problems in the past eleven years and report the research gaps. To this end, first, the related research was classified based on the shop environments. Then, after reviewing the existing papers and summarizing them, future researches and emerging research fields of the multi-factory scheduling problem are reported. This review indicates that future research should focus on open shop production environments. The results also show only 4% of the papers focus on the virtual alliance. Therefore, researchers need to consider the virtual alliance in the production network and investigate the participation and competition between the partners in such network. Studying the topic of Industry 4.0 in multi-factory scheduling and subsequently investigating the related topics such as information sharing and real-time data are also the new trends in this field. Considering the complex series–parallel structures in the multi-factory production and defining objective functions related to environmental issues such as reducing pollutants and noise are other suggestions for future studies.

**Keywords** Multi-factory scheduling · Distributed production network · Systematic review · New trends

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## 1 Introduction

In recent years, dispersing and distribution of production activities have attracted the attention of competing organizations in global markets (Naderi and Ruiz 2014). In this environment, to increase competitiveness and respond to market changes, the factories have changed their production systems from a single factory to a multi-factory. The multi-factory production system is one of the production systems that has received much attention from researchers and industries in the same period. Leung et al. (2003) have raised a practical example of multi-factory production problems. They studied a multi-national clothing manufacturer in Hong Kong. The manufacturing company produces a number of products and distributes them in North America and Europe. The company's factories are located in different countries, including China, the Philippines, Thailand, and other Southeast Asian countries. Therefore, efficient scheduling is essential for factories to stay in a competitive environment to respond to market changes. At the beginning of the current century, this problem has been considered simultaneously in both the industry and the academic environment. For the following reasons, traditional manufacturing systems are unable to respond to these markets (Gao 2011).

- The response time to random changes in the market is not satisfactory.
- Inadequate and inaccurate information due to the geographical magnitude of the distribution of customers has caused decision-makers to make decisions based on intuition or very little information.
- The organizational structure of traditional systems is predetermined and inflexible. Therefore, they are not flexible against new markets and their changes.

Therefore, in order to overcome these drawbacks, several factories cooperate with each other. Although the scheduling of such a multi-factory production network is much more complicated than single factory scheduling problems, due to its wide range of applications in industry, in the past few years, research on the distributed environments in multi-factory production networks has been one of the most attractive topics (Chung et al. 2009).

There are two types of distribution networks in a multi-factory environment: (i) all factories belong to an organization and they work together to maximize the profits of that single organization, and (ii) a number of independent factories establish a multi-agent production network with the virtual alliance. This network is called a production network with the virtual alliance or multi-agent production network. In this case, the purpose of creating such a virtual alliance is to achieve greater benefits for each member of the network compared to individual production. In both above cases, if distributed activities are properly managed and organized, the virtual production network can reduce production costs and increase flexibility and efficiency (Shi and Gregory 2003). It is clear that distributed scheduling problems are much more complicated than classical scheduling; because two decisions have to be made: allocating jobs to appropriate factories and determining the jobs' scheduling considering one or more objective functions. Since there are many significant applications of the multi-factory production system in real-world problems, e.g., energy-producing industries (Westfield 1955), auto manufacturers (Gnoni et al. 2003), food and chemical processing industries (Timpe and Kallrath 2000) steel companies (Sambasivan and Yahya 2005) and drug manufacturing (Beheshtinia et al. 2018), this problem has attracted the attention of many researchers.

This study reviews the papers related to the distributed production network scheduling that have been done in recent years. In fact, as a continuation of Behnamian and Fatemi Ghomi (2016), it is the second comprehensive review on the problem of multi-factory production network scheduling. In that review, they surveyed the multi-factory scheduling researches was from 1989 to 2011. In this paper, first, the literature is classified based on the nature of the shop configuration into five aspects, *i.e.*, single machine, parallel machines, flowshop, job shop, and open shop. Then based on this classification, the related papers are review and finally, after summarizing and analyzing them, several future research trends are introduced.

The remains of the paper are organized as follows: Sect. 2 presents the research methodology and classification of the multi-factory production system. Section 3 reviews the multi-factory scheduling papers according to the presented classification. The literature review is analyzed in Sect. 4. Finally, Sect. 5 discusses the conclusions and the emerging research fields in a multi-factory scheduling problem.

## 2 Research methodology and classification

In this section, the research methodology and the classification of multi-factory scheduling problem are presented. There are two general research methodologies for writing a review paper, (i) systematic structure (Snyder 2019), (ii) concept-centric structure, introduced by Webster and Watson (2002). In the concept-centric structure, the subject is expressed in a conceptual framework. In this structure, a matrix is compiled as papers are read. As the reading goes on, the key concepts are grouped logically, and the literature is synthesized by discussing the identified concepts. Then, analyses are performed using classified concepts. But, in the systematic structure, the review was done systematically by identifying, evaluating, collecting, and analyzing data from past researches (Liberati 2009). This structure was first used in medical research, but in recent years, it has also been widely used in other scientific fields of research. In fact, this type of review is carried on using resource search, predefined inclusion and exclusion criteria, evaluation, extraction, and generation of data (Snyder 2019). Based on the above explanations and considering systematic classifications of shop environments in scheduling problems, the systematic structure seems more suitable for the present review. So, in this paper, a systematic review structure is used, and its purpose is to summarize and analyze the results and, identify research gaps in the past research on distributed scheduling.

Although no limitation on the production environment was applied, based on the (Baker and Trietsch 2013), references were categorized based on the shop environments, including single machine, parallel machines, flowshop, and job shop. In this regard, at first, the literature was searched mainly on major databases such as Springer-Link, Science Direct, IEEE Xplore, Scopus, and other web sources up to 2021. All the mentioned databases were searched for references with “multi-factory”, “multi-agent”, and “distributed scheduling” in their titles and keywords. Then, some of the searched papers were removed due to their irrelevant content or publication time. Since this paper is a continuation of Behnamian and Fatemi Ghomi (2016), the papers published before 2011 were excluded from search results. Finally, the results are analyzed and based on their summaries, the research gaps and new trends are provided.

### 3 Literature review

In recent years, the production scheduling problem has been studied by many researchers, that in most of them, the non-distributed scheduling problems as classic planning have been studied. The first research on the multi-factory distributed scheduling problem was done out by Williams (1981) in 1981. In this research, joint scheduling in production and distribution problem in complex networks with the objective of minimizing production and distribution costs has been investigated.

Many studies have so far been conducted in the field of distributed scheduling problems. In the following, the papers associated with each of the produced environments have been investigated according to the presented category.

#### 3.1 Single machine

The simplest scheduling problem is the single machine scheduling problem. There is only one machine or source in this production system. In practice, scheduling problems in more complex environments are decomposed into single machine sub-problems (Pinedo 2012). In this regard, Macarthur et al. (2011) proposed a decentralized task distribution algorithm (DTDA). They analyzed the scheduling of unrelated parallel machines and the multi-agent task allocation. Ruifeng and Subramaniam (2011) divided the multi-stage system into a number of subsystems and solved each of them by a discrete Markov process. They proposed an approximate model to minimize operational costs for the multi-plant production system. They assumed that the amount of inventory in each buffer was controlled by the system (S, Q).

Sun et al. (2015) studied the integrated problem of production and distribution of multi-factories and multi-products with considering marine constraints. They developed a mixed-integer planning model with the objectives of minimizing production cost, warehouses cost, transportation cost, and penalty cost. To solve this problem, they introduced a heuristic algorithm called due-date based cut-off rule (DBC). Also, they proposed a genetic algorithm (GA) that is guided by a fuzzy controller. Karimi and Davoudpour (2017a) studied the integrated problem of scheduling and transportation in a supply chain with a series structure. The objective of the problem is to minimize the sum of inventory and transportation costs. They assumed that inventory maintenance cost is dependent on the production stage and transportation and delivery of jobs among factories are allowed. They proposed a mixed-integer programming (MIP) model as well as a time-indexed formulation. Also, they proposed a relaxation model and an approximate algorithm for this problem. In another paper, they studied the multi-factory production system problem in the series environment considering the various delivery deadlines (Karimi and Davoudpour 2017b). They proposed a knowledge-based imperialistic competitive algorithm to determine the number of batches, assign jobs to batches, and scheduling the batches production and delivery in each factory.

Marandi and Fatemi Ghomi (2019a) developed a MIP model for the integrated multi-factory production and distribution scheduling, applying the vehicle routing approach to minimize the total tardiness and transportation costs. To solve this problem, they proposed an improved imperialist competitive algorithm (ICA). In another paper (Marandi and Fatemi Ghomi 2019b), they studied the multi-factory scheduling problem with batch delivery. They developed a MIP model to minimize the sum of transportation cost, maintenance

cost, and delay cost. Furthermore, due to the complexity of the problem, they proposed a learning-oriented simulated annealing algorithm and a hybrid cloud theory-based learning-oriented simulated annealing (HCLSA) algorithm. Gharaei and Jolai (2019) proposed a mathematical model for the integrated scheduling and distribution problem in a multi-factory environment considering batch delivery and routing decisions between customers. They proposed the multi-agent approach to solve the problem. Due to the complexity of the problem, they presented a multi-objective ant colony optimization (ACO) algorithm. They also used a simulated annealing algorithm to improve the quality of the solutions of the proposed algorithm.

These papers are summarized in Table 1.

### 3.2 Parallel machines

In this environment, two sub-problems should be solved, i.e., (i) assigning the job to the factory, and (ii) scheduling the job in each factory. In this regard, Terrazas-Moreno and Grossmann (2011) studied a distributed production network, which consists of several factories with parallel structures. They developed a MIP model to minimize operational costs. To solve the problem, they used two decomposition methods. In the first one, a bi-level decomposition was extended to multi-site multi-market networks and, in the second method, they applied a combination of the multi-level decomposition method with the Lagrangian relaxation method. Behnamian and Fatemi Ghomi (2013) studied the multi-factory production scheduling problem with considering communications policies. They assumed that the factories had been located geographically in different places. In this problem, they assumed machines in the factories have different speeds. To minimize the makespan, they proposed a MIP model and the longest processing time-based heuristic algorithm and GA. Furthermore, they proposed a lower bound for this problem. For this problem, Behnamian (2014) proposed mixed-integer linear programming and solved it with the improved  $\epsilon$ -constraint method. To solve the problem, the author proposed a decomposition method based on hybrid variable neighborhood search (VNS) and tabu search (TS) algorithms to minimize the cost of job processing and maximize production profit. In this paper, it is assumed that the factories are independent. In another research, Behnamian (2017a) studied distributed scheduling problem with parallel factories. In this paper, it is assumed that jobs can be transferred from the factory with more workload to the factory with less workload. For the first time, the author proposed a metaheuristic algorithm based on the electromagnetism-like algorithm and benders decomposition algorithm to minimize the production costs. Behnamian (2016) proposed a graph coloring-based algorithm to scheduling a parallel job in the multi-factory scheduling problem with parallel structure. In this problem, jobs can be transferred between factories to balance the workloads in the production network. In the proposed approach, first, jobs are decomposed into several sets of the job through semidefinite programming and rounding algorithm and, then, for scheduling the set of jobs generated in the first stage, a particle swarm optimization (PSO) algorithm was proposed. Behnamian (2017b) proposed a MIP model for the problem of distributed production network with heterogeneous parallel factories distributed in different geographical places. In this research, the author proposed a new method called anarchic particle swarm optimization (APSO) to minimize the makespan. In this research, the proposed algorithm is inspired by the anarchic behavior of a society. Lei et al. (2020a) studied distributed scheduling problem in the heterogeneous production network. They assumed that the manufacturing system has unrelated parallel machines. To minimize the makespan,

**Table 1** Multi-factory scheduling with single machine environment

References	Distribution network type		Model	Objective		Category of solution methods			Comments	
	Central- owned- ownership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic
Macarthur et al. (2011)	✓		-	Makespan			✓			Solution method: DTDA
Ruifeng and Subramaniam (2011)	✓		✓	Makespan		✓				Solution method: Approximate method
Sun et al. (2015)	✓		✓	Operational costs				✓		They proposed a GA that is guided by a fuzzy controller Costs include: production cost, warehouses cost, transportation cost and penalty cost
Karimi and Davoudpour (2017a)	✓		✓	Operational costs		✓			✓	Solution method: DBC/ GA They developed a MIP model and a time-indexed formulation Solution method: A linear programming relaxation model and an approximate algorithm

Table 1 (continued)

References	Distribution network type		Model	Objective	Category of solution methods			Comments	
	Central- owned- ownership	Virtual alliance			Approximate	Exact	Metaheuristic		Heuristic
Karimi and Davoudpour (2017b)	✓		✓	Operational costs		✓			Costs include: transportation costs and tardiness costs Solution method: KBICA
Marandi and Fatemi Ghomi (2019a)	✓		✓	Operational costs		✓			Considering vehicle routing approach Costs include: transportation costs and tardiness costs Solution method: IICA
Marandi and Fatemi Ghomi (2019b)	✓		✓	Operational costs		✓		✓	Batch delivery Costs include: total tardiness, transportation and holding costs Solution method: SA/HCLSA

**Table 1** (continued)

References	Distribution network type		Model	Objective		Category of solution methods			Comments
	Central- owned- ownership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic	
Gharaei and Jolai (2019)	✓		✓	-	✓			✓	<p>Considering batch delivery and routing decisions between customers</p> <p>Use of a multi-agent approach</p> <p>First agent: Minimizing operational costs,</p> <p>Second agent: Minimizing tardiness</p> <p>Solution method: ACO</p>



they proposed a mathematical model and an imperialist competitive algorithm (ICA) with memory.

Liu and Lei (2020) studied distributed unrelated parallel machines scheduling problem considering preventive maintenance constraints. They proposed an artificial bee colony with a division (DABC) algorithm for the problem. In the proposed algorithm, the swarm is divided into one employed bee colony and three onlooker bee colonies. Behnamian and Fatemi Ghomi (2020) addressed the multi-factory scheduling problem with heterogeneous factories. In this problem, the factories available to process the jobs have different speeds in which each factory has identical parallel machines. To minimize the sum of the earliness and tardiness ( $E/T$ ) and total completion time, they proposed a mixed-integer linear program model and a heuristic algorithm. Pan et al. (2020) proposed a knowledge-based two-population optimization algorithm for the distributed parallel machines scheduling with the objectives of minimizing the total energy consumption and total tardiness. They used two methods based on problem-specific knowledge and a random heuristic for the initial solutions. Lei et al. (2020b) proposed an improved artificial bee colony for the multi-objective distributed production network with the unrelated parallel machines. To perform the search process in the stages of the employed bee and onlooker bee in the proposed algorithm, they applied different combinations of searches of global and neighborhood. For the first time, Wachtel and Elalouf (2020) proposed a fully polynomial approximation scheme (FPAS) approximation method for job assignment in a multi-factory environment. The proposed method is very general and is used for various objective functions.

These papers are summarized in Table 2.

### 3.3 Flow shop

The flowshop scheduling problem is one of the most well-known scheduling problems. This problem has been attracted many researchers in recent decades. This production system has many applications, such as semiconductor industries, electronics, aircraft engine production, and petrochemicals.

Gao and Chen (2011) addressed the distributed permutation flowshop scheduling problem with the objective of minimizing the maximum completion time. In this problem, the considered multi-factory production system has a parallel structure. Due to the complexity of the problem, they proposed a hybrid algorithm based on the GA and three local search algorithms. Naderi and Ruiz (2014) presented a scatter search (SS) algorithm to minimize the makespan. Wang et al. (2016) studied this problem considering the machine breakdown. In order to minimize the makespan, they proposed a fuzzy logic-based hybrid estimation of distribution algorithm. Also, to preserve population diversity, they proposed a fuzzy logic-based adaptive evolution strategy. Deng et al. (2016) proposed an improved harmony search algorithm for the distributed two machines flowshop scheduling problem. They developed a two-step decoding method for solution representation. The distributed no-wait flowshop scheduling problem for the first time was investigated by Lin and Ying (2016). In order to minimize the makespan, they proposed a MIP model and iterated cocktail greedy (ICG) algorithm. Deng and Wang (2017) proposed a competitive memetic algorithm (CMA) to solve the distributed permutation flowshop scheduling problem with the objective of minimizing the makespan and total tardiness. Cai et al. (2018) studied this problem with transportation and eligibility constraints. They proposed a mathematical model with the objectives of minimizing the makespan, maximum lateness, transportation costs, and setup costs. They developed several heuristic algorithms for solving the

**Table 2** Multi-factory scheduling with the parallel machines production environment

References	Distribution network type		Model	Objective		Category of solution methods			Comments		
	Central- owned ownership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic	Hybrid
Terrazas-Moreno and Grossmann (2011)	✓		✓	Operational costs		✓					Solution method: Two methods of decomposition
Behnamian and Fatemi Ghomi (2013)		✓	✓	Makespan			✓				Solution method: a lower bound Machines in factories have different speeds
Behnamian (2014)		✓	✓	-					✓		Solution method: GA and heuristic algorithm Objectives: Minimization of the total processing cost, maximization of the production profits Solution method: Decomposition-based hybrid VNS-TS algorithm

Table 2 (continued)

References	Distribution network type		Model	Objective	Category of solution methods			Comments				
	Central- owned- ownership	Virtual alliance			Single objective	Multi-objective	Approximate		Exact	Metaheuristic	Heuristic	Hybrid
Behnamian (2017a)	✓	✓	✓	Production costs			✓					Jobs can be transferred from the factory with more workload to the factory with less workload
Behnamian (2016)	✓		–	Makespan			✓					Solution method: Matheuristic
Behnamian (2017b)		✓	✓	Makespan			✓					Jobs can be transferred between factories
												Solution method: A graph coloring-based algorithm
												The proposed algorithm is inspired by the anarchic behavior of a society
Lei et al. (Lei et al. 2020a)	✓		✓	Makespan			✓					Solution method: APSO
												Solution method: MICA

**Table 2** (continued)

References	Distribution network type		Model	Objective		Category of solution methods			Comments	
	Central- owned ownership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic
Liu and Lei (2020)	✓		✓	Makespan			✓			Considering preventive maintenance constraint Solution method: DABC
Behnamian and Fatemi Ghomi (2020)	✓		✓	-	✓			✓		Objectives: Minimizing the total completion time, and the sum of the E/T Solution method: Heuristic algorithm
Pan et al. (2020)	✓		-	-	✓			✓		Objectives: Minimizing the total energy consumption and total tardiness Solution method: A knowledge-based two-population algorithm

**Table 2** (continued)

References	Distribution network type		Model	Objective		Category of solution methods			Comments	
	Central- ized own- ership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic
Lei et al. (2020b)	✓		-	-	-	✓				Objectives: Mini- mizing makespan and total tardi- ness Solution method: Improved artifi- cial bee colony Solution method: FPTAS
Wachtel and Ela- louf (2020)	✓		-	-	-		✓			

single-objective problem and a GA for solving the multi-objective problem. Zhang and Xing (2018) addressed the distributed two-stage assembly flowshop scheduling problem. In this paper, to minimize the total completion time, they proposed a memetic algorithm (MA) based on the social spider optimization (SSO) algorithm. Also, Lei and Li (2020c) proposed a cooperated teaching–learning-based optimization (CTLBO) to solve this problem. Huang et al. (2021) presented an improved iterative greedy algorithm based on the groupthink (gIGA) for distributed assembly permutation flowshop scheduling problem with the objective of minimizing the total flow time. Song and Lin (2021) developed a genetic programming hyper-heuristic (GP-HH) algorithm for the distributed assembly permutation flow shop scheduling problem with sequence dependent setup time. To minimize the maximum completion time of this problem, Zhang et al. (2021) developed a matrix-cube-based estimation of distribution algorithm (MCEDA).

Ruiz et al. (2019) proposed two improved iterated greedy algorithms to solve the distributed permutation flowshop scheduling problem. Pan et al. (2019a) studied this problem with the total flowtime objective function. To solve the problem, they proposed three heuristic algorithms and four metaheuristic algorithms (discrete artificial bee colony (DABC), scatter search (SS), iterated greedy (IG), and iterated local search (ILS)). Lin and Zhang (2016) studied the distributed assembly permutation flowshop scheduling problem. They proposed a hybrid biogeography-based optimization (HBBO) algorithm to minimize the makespan. Furthermore, to improve the hybrid algorithm, they proposed a local search algorithm. Pan et al. (2019b), in another research, developed a MIP model with the objective of minimizing the makespan for this problem. Due to the complexity of the problem, they proposed three heuristic algorithms, two VNS algorithms, and an iterative greedy algorithm. Hatami et al. (2013) developed a MIP model for this problem with the objective of minimizing the makespan. Due to the Np-hardness of this problem, the authors suggested three heuristic algorithms and a variable neighborhood descent (VND) algorithm. In another paper, Hatami et al. (2014) proposed two simple algorithms. Wang and Wang (2016) proposed an estimation of the distribution-based memetic algorithm to solve this problem. Gonzalez-Neira et al. (2017) studied this problem with random processing and assembly times. They proposed a hybrid algorithm based on simulation methods to solve this problem. To solve this problem, Zhang and Yin (2020) proposed a GA in which a greedy mating pool and an effective crossover strategy based on the local search were used. Zhang et al. (2020) proposed a MIP model and a MA to solve the distributed flexible assembly permutation flowshop scheduling problem to minimize the makespan. Li et al. (2021a) studied the distributed assembly flow shop scheduling with fuzzy processing time. To minimize the fuzzy makespan, they developed an imperialist competitive algorithm with empire cooperation (ECICA). Rifai et al. (2016) studied a multi-objective adaptive large neighborhood search (MOALNS) algorithm for the distributed permutation flowshop scheduling problem. They developed a MIP model with the objectives of minimizing the makespan, total costs, and average tardiness. Zhang et al. (2018a) studied the distributed flowshop scheduling problem considering the flexible assembly operation and setup time. They developed a mathematical model with the objective of minimizing the makespan. This problem consists of four decisions: assigning jobs to factories, determining the sequence of jobs in each factory, determining an assembly machine for each product, and determining the sequence of products on each assembly machine. To solve the problem, they proposed a heuristic algorithm and a hybrid metaheuristic algorithm entitled the HPSO and HVNS algorithms.

Fu et al. (2019a) studied the stochastic flowshop scheduling problem in a distributed manufacturing system. To minimize the objective functions, total tardiness, and energy

consumption, they proposed a multi-objective mathematical model. Furthermore, due to the complexity of the problem, the authors proposed a brain storm optimization (BSO) algorithm. In another paper, Fu et al. (2019b) studied this problem considering the makespan and total energy consumption objective functions. They proposed a multi-objective mathematical model with the chance constraint. Bargaoui et al. (2017) studied the distributed permutation flowshop scheduling problem in the multi-factory environment. To solve this problem by considering the multi-agent systems, they proposed an evolutionary algorithm based on the chemical reaction optimization (CRO) algorithm. Zhang et al. (2018b) proposed a discrete differential evolution algorithm (DDE) for this problem with blocking. They used four heuristic algorithms to generate the initial population. Fernandez-Viagas et al. (2018), to minimize the total flowtime, proposed eighteen heuristic algorithms and an evolutionary algorithm (EA). Wang et al. (2019) investigated the multi-objective problem by considering the sequence-dependent setup time (SDST). To minimize the makespan and total energy consumption, they proposed a multi-objective MIP model and a multi-objective whale swarm algorithm (MOWSA). Shao et al. (2019) studied the multi-objective distributed no-wait flowshop scheduling problem with SDST. They developed a MIP model with the objectives of minimizing the makespan and the total weight tardiness for it. To solve the problem, they also proposed a Pareto-based estimation of distribution algorithm (PEDA) and a heuristic algorithm for generating the initial population. Chen et al. (2019) developed a MIP model for the distributed heterogeneous flowshop scheduling. To minimize the makespan, they proposed a probability model-based memetic algorithm (PMMA). Meng et al. (2019) studied the distributed scheduling problem in the permutation flowshop production environment with the customers' order constraint. In this problem, they assumed a set of customer orders needs to be manufactured in a number of factories and each order composed of some defined jobs should be processed in the same factory. In order to minimize the makespan, they developed a mathematical model and proposed three heuristic and three metaheuristic algorithms. Chen et al. (2019b) studied the energy-efficient distributed no-idle permutation flow shop scheduling problem to minimize makespan and total energy consumption. To solve this problem, they proposed a collaborative optimization algorithm (COA).

Zhao et al. (2020) proposed an ensemble discrete differential evolution (EDE) algorithm and a MIP model for distributed blocking flowshop scheduling problem (DBFSP). Also, for this problem, Shao et al. (2020a) proposed a hybrid enhanced discrete fruit fly optimization algorithm (HEDFOA) in the blocking flowshop environment. To initialize the common central location of all fruit fly swarms, they proposed an efficient heuristic. Shao et al. (2021a) studied the distributed permutation flow shop scheduling problem considering the mixed blocking. To minimize the makespan, they proposed an improved NEH heuristic and efficient iterated greedy (EIG) algorithm. In another research, Shao et al. (2020b) assumed the processing times to be fuzzy. To solve this problem with the objective minimize the fuzzy makespan, they proposed two new heuristic algorithms based on the problem-specific knowledge and the NEH heuristic and two iterated greedy (IG) algorithms to minimize the fuzzy makespan. Chen et al. (2021) considered a distributed flowshop scheduling problem with blocking. They proposed six heuristic algorithms and an iterated greedy (IG) algorithm to minimizing the makespan. Wang et al. (2020) proposed a multi-objective MIP model to minimize makespan and energy consumption. They developed a new problem-dependent local search algorithm to improve the exploitation capability of the multi-objective whale swarm algorithm. Hamzadayi (2020) developed a new mathematical model and hybrid Benders decomposition algorithms for solving the distributed permutation flowshop scheduling problem (DPFSP). For the first time, Jing et al. (2020)

considered due windows in the distributed permutation flowshop scheduling problem. To minimize the total weighted E/T, they presented an iterated greedy (IG) algorithm. Also, they proposed an adapted NEH heuristic to generate an initial solution. In another paper, they (Jing et al. 2021) modeled a robust distributed permutation flowshop problem. They assumed processing times to be uncertain. To solve, the authors presented a new iterated greedy algorithm (IGA) and a new iterated local search algorithm (ILS) to minimize the makespan. They used an NEH heuristic algorithm to initialize the proposed algorithms. Khare and Agrawal (2020) modeled a distributed permutation flowshop scheduling problem with the objective of minimizing total tardiness. To solve the problem, they proposed two heuristic algorithms, hybrid discrete Harris hawks optimization and an enhanced variant of iterated greedy algorithm. To more easily solve the distributed permutation flowshop scheduling problem, Yang et al. (2020) used a helper objective to turn the single-objective problem into a multi-objective problem. They presented an improved swarm intelligence optimization algorithm to solve both objective functions (original and helper goal). Liu (2020) considered the distributed flowshop group scheduling problem with the objectives of minimizing total flowtime. The author proposed twenty heuristic algorithms, including eight simple heuristics, eight hybrid heuristics, and four NEH-based heuristics to solve this problem. Ali (2020) proposed a mathematical model and a construction heuristic and tabu search algorithm to solve the permutation flowshop scheduling problem to minimize makespan. The author considered assumptions of no-wait and heterogeneous in the problem. Mao et al. (2021) proposed an effective multi-start IGA for the distributed permutation flow shop scheduling problem considering preventive maintenance operation. They used a heuristic algorithm to improve initialization. Also, to prevent falling into the local optima, they presented a destruction phase and a construction phase. For the first time, Rifai et al. (2021) considered sequence-dependent setup time in distributed reentrant permutation flow shop problem. They proposed a multi-objective adaptive large neighborhood search (MOALNS) to solve this problem. Baysal et al. (2021) proposed an artificial bee colony algorithm to solve the distributed fuzzy permutation flow shop scheduling problem. The authors assumed the due dates of the jobs and processing time of the jobs to be trapezoidal fuzzy numbers and triangular fuzzy numbers, respectively. Meng and Pan (2021) considered the lot-streaming and carryover SDST in the distributed permutation flowshop scheduling problem. Factories of the problem are heterogeneous. They proposed an enhanced artificial bee colony algorithm (NEABC) to minimize the makespan. Ali et al. (2021) formulated distributed permutation flowshop scheduling problem. To minimize the total completion time, they proposed the TS algorithm. Li et al. (2021b) considered the mixed no-idle constraints in the distributed flow shop scheduling problem. In this research, they proposed a MIP model and an adaptive iterated greedy (AIG) algorithm to minimize total flow time. They used a restart strategy to prevent falling into the local optima. Li et al. (2021c) considered the heterogeneous factories in the distributed no-wait flowshop scheduling problem. Factories have a different number of machines, machine technology, raw material supply, and transportation conditions. They presented the discrete artificial bee colony algorithm (DABC) to minimize the makespan. In the proposed algorithm, they used the variable neighborhood descent (VND) algorithm to increase the search of the algorithm in the solution space. Isguder and Hamzaday (2021) proposed two new mathematical models by inspiration from the models of the multiple-traveling salesman problem (mTSP). They developed six different Benders decomposition algorithms and a hybrid Benders decomposition algorithm.

For the first time, Ying and Lin (2018) studied the distributed hybrid flowshop scheduling problem with multiprocessor tasks. To solve the problem, they proposed a MIP model



and a self-tuning iterated greedy algorithm (sIGA) to minimize the makespan. In the proposed algorithm, the adaptive cocktail decode method was used. Li et al. (2020) proposed a machine position-based mathematical model and a discrete artificial bee colony algorithm (DABC) for the distributed hybrid flowshop scheduling problem with SDST. They proposed two heuristic algorithms and a random strategy for generating the initial solution. To minimize the makespan and the maximum of the total agreement index, Cai et al. (2020) proposed a collaborative variable search (CVS) for solving the fuzzy distributed two-stage hybrid flowshop scheduling problem with SDST. In another paper (Cai et al. 2020a), they proposed a dynamic shuffled frog-leaping algorithm (DSFLA) to minimize makespan in the distributed hybrid flowshop scheduling problem. Also, they developed a lower bound for this problem. Cai et al. (2020b) studied the bi-objective distributed scheduling in the hybrid flowshop. They proposed a shuffled frog-leaping algorithm with memplex quality (MQSFLA) to minimize total tardiness and makespan. Wang and Li (2020) studied a fuzzy distributed hybrid flow shop problem. To minimize the makespan and the fuzzy total energy consumption and maximize the total agreement index, they proposed the shuffled frog leaping algorithm with the collaboration of multiple search strategies (SFLA-CMSS). Lei and Wang (2020) studied the distributed scheduling problem in a two-stage hybrid flowshop environment to minimize makespan and the number of tardy jobs. In this problem, setup time is assumed sequence-dependent. To solve this problem, they proposed a shuffled frog-leaping algorithm with memplex grouping. Shao et al. (2020c) developed a mathematical model for distributed hybrid flow shop scheduling problem. To minimize the makespan, they proposed two algorithms called DNEH with smallest-medium rule algorithm and the multi-neighborhood iterated greedy algorithm. Cai and Lei (2021) modeled a distributed hybrid flow shop scheduling with fuzzy processing time. The considered objective functions for this problem were (i) minimize the makespan, (ii) minimize the fuzzy total energy consumption, and (iii) maximize the total agreement index. Also, to solve this problem, they proposed a cooperated shuffled frog-leaping algorithm (CSFLA). Wang and Wang (2020) studied the distributed hybrid flow shop scheduling problem to minimize the makespan. The authors assumed factories to be heterogeneous. To solve the problem, they proposed a bi-population memetic algorithm. Shao et al. (2021b) considered a distributed hybrid flow shop scheduling. To minimize the makespan, total weighted E/T and total workload, they proposed a multi-objective evolutionary algorithm. Their proposed algorithm was based on multiple neighborhood local searches. Wu and Xia (2021) developed two models for the distributed flow shop scheduling problem and reentrant scheduling problem in the manufacturing of seamless steel tubes. To solve these problems, they used the fruit fly optimization method and simulated annealing algorithm, respectively.

The reviewed papers are summarized in Table 3.

### 3.4 Job shop

The job shop scheduling problem is one of the most important topics in production management and is one of the most complex topics in combinatorial optimization. In this environment, each job consists of several operations and it has its own production route.

The distributed job shop scheduling problem is investigated for the first time by Jia et al. (2002). The aim of this problem is to determine the most appropriate factory problem for each job (assignment), determine the most appropriate machine problem for each job (routing), and determine the operation sequences on each machine (sequence). In this paper, a web-based system is proposed for production scheduling to facilitate the collaboration

**Table 3** Multi-factory scheduling with flowshop production environment

References	Distribution network type		Model	Objective		Category of solution methods			Comments	
	Central- owned ownership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic
Gao and Chen (2011)	✓		-	Makespan					✓	The local search algorithm uses three rules Solution method: GA-LS Solution method: SS
Naderi and Ruiz (2014)	✓		-	Makespan			✓			
Wang et al. (2016)	✓		-	Makespan					✓	Considering the machine break-down Solution method: Fuzzy logic-based hybrid estimation of distribution algorithm (EDA)
Deng et al. (2016)	✓		-	Makespan				✓		Two-machine flowshop environment Solution method: improved harmony search algorithm
Lin and Ying (2016)	✓		✓	Makespan				✓		No-wait flowshop production environment Solution method: ICG

**Table 3** (continued)

References	Distribution network type		Model	Objective		Category of solution methods			Comments	
	Central- ized own- ership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic
Deng and Wan (2017)	✓		-		-	✓				Objectives: minimizing makespan and total tardiness Solution method: CMA
Cai et al. (2018)	✓		✓		-	✓				Objectives: minimizing makespan, maximum lateness and total costs maximum lateness and total costs Proposed a number of heuristic algorithms with a single objective Solution method: NSGA-II
Zhang and Xing (2018)	✓		-		Total completion time			✓		Two-stage assembly flowshop production environment Solution method: MA based on the SSO

**Table 3** (continued)

References	Distribution network type		Model	Objective		Category of solution methods			Comments	
	Central- owned- ownership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic
Lei and Li (2020c)	✓	-	-	Makespan		✓				Solution method: CTLBO
Huang et al. (2021)	✓	-	-	Total flow time		✓				Solution method: gIGA
Song and Lin (2021)	✓	-	-	Makespan		✓				Considering SDST Solution method: GP-HH
Zhang et al. (2021)	✓	-	-	Makespan		✓				Solution method: MCEDA
Ruiz et al. (2019)	✓	-	-	Makespan		✓				Solution method: ICA
Pan et al. (2019a)	✓	-	-	Total flow time		✓		✓		Solution method: Three new heuristic algorithms and four new metaheuristic algorithms
Lin and Zhang (2016)	✓	-	✓	Makespan					✓	Assembly permutation flowshop production environment Solution method: HBBO

**Table 3** (continued)

References	Distribution network type		Model	Objective	Category of solution methods			Comments
	Central-ized own-ership	Virtual alliance			Approximate	Exact	Metaheuristic	
Pan et al. (2019b)	✓		✓	Makespan		✓	✓	Assembly permutation flowshop production environment Solution method: Three heuristic algorithms/ VNS/ IGA
References	Distribution network type		Model	Objective	Category of solution methods			Comments
	Central-ized own-ership	Virtual alliance			Approximate	Exact	Metaheuristic	
Hatami et al. (2013)	✓		✓	Makespan		✓	✓	Assembly permutation flowshop production environment Use of the ANOVA test Solution method: Three heuristic algorithms/ VND

**Table 3** (continued)

References	Distribution network type		Model	Objective		Category of solution methods			Comments	
	Central- owned ownership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic
Hatami et al. (2014)	✓		–	Makespan					✓	Assembly permutation flowshop production environment Solution method: Two simple effective algorithms
Wang and Wang (2016)	✓		–	Makespan			✓			Assembly permutation flowshop production environment Solution method: An estimation of distribution memetic-based algorithm
Gonzalez-Neira et al. (2017)	✓		–	Makespan					✓	Assembly permutation flowshop production environment Solution method: Hybrid algorithm

**Table 3** (continued)

References	Distribution network type		Model	Objective	Category of solution methods			Comments
	Central- owned- ownership	Virtual alliance			Approximate	Exact	Metaheuristic	
Zhang and Yin (2020)	✓		–	Makespan		✓		Assembly permutation flowshop production environment Solution method: GA
Zhang et al. (2020)	✓		✓	Makespan		✓		Solution method: An efficient memetic algorithm
Li et al. (2021a)	✓		–	Fuzzy makespan		✓		Considering fuzzy processing time Solution method: ECICA
Rifai et al. (2016)	✓		–	–	✓			Objectives: Minimizing costs and average tardiness Solution method: MOALNS

**Table 3** (continued)

References	Distribution network type		Model	Objective		Category of solution methods			Comments	
	Central- owned- ownership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic
Zhang et al. (2018a)	✓		✓	Makespan				✓		Considering the flexible and setup time
Fu et al. (2019a)	✓		✓	-			✓			Solution method: a heuristic algorithm and HPSO, HVNS Objectives: Minimizing total tardiness and energy consumption Modeling in non-deterministic mode Solution method: BSO



**Table 3** (continued)

References	Distribution network type		Model	Objective	Category of solution methods			Comments				
	Central-ized own-ership	Virtual alliance			Single objective	Multi-objective	Approximate		Exact	Metaheuristic	Heuristic	Hybrid
Fu et al. (2019b)	✓		✓	-		✓						Objectives: Minimizing makespan and energy consumption Considering the chance constraint Presenting the model in non-deterministic mode Solution method: multi-objective brain storm optimization algorithm
Bargaoui et al. (2017)	✓		-	Makespan				✓				Proposed an evolutionary algorithm based on the chemical reaction optimization algorithm and multi-agent systems Solution method: An evolutionary algorithm based on CRO algorithm

**Table 3** (continued)

References	Distribution network type		Model	Objective		Category of solution methods			Comments	
	Central- owned ownership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic
Zhang et al. (2018b)	✓		–	Makespan			✓			Solution method: DDE
Fernandez-Viagas et al. (2018)	✓		–	Total flow time			✓			Solution method: Eighteen heuristic algorithms/EA
References	Distribution network type		Model	Objective		Category of solution methods			Comments	
	Central- owned ownership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic
Wang et al. (2019)	✓		✓	–			✓			Objectives: minimize the makespan and total energy consumption Solution method: MOWSA

**Table 3** (continued)

References	Distribution network type		Model	Objective	Category of solution methods			Comments
	Central- owned- ownership	Virtual alliance			Approximate	Exact	Metaheuristic	
Shao et al. (2019)	✓		✓	-		✓		No-wait flowshop production environment Objectives: minimizing makespan and the total weight tardiness Presentation of a heuristic for the initial population Solution method: PEDDA
Chen et al. (2019)	✓		✓	Makespan		✓		Heterogeneous factories Solution method: PMMA
Meng et al. (2019)	✓		✓	Makespan		✓	✓	Proposed methods for improving the proposed algorithms Solution method: Three heuristic algorithms and three metaheuristics

**Table 3** (continued)

References	Distribution network type		Model	Objective	Category of solution methods			Comments			
	Central- owned- ownership	Virtual alliance			Single objective	Multi-objective	Approximate		Exact	Metaheuristic	Heuristic
Chen et al. (2019b)	✓		✓	-		✓					Objectives: minimizing makespan and energy consumption Solution method: COA
Zhao et al. (2020)	✓		✓	Makespan		✓					Blocking flowshop production environment Solution method: EDE
Shao et al. (2020a)	✓		-	Makespan						✓	Solution method: HEDFOA
Shao et al. (2021a)	✓		-	Makespan					✓		Solution method: An improved NEH heuristic/EIG
Shao et al. (2020b)	✓		-	The fuzzy makespan					✓		Considering fuzzy processing time Solution method: Two new heuristics and two iterated greedy
Chen et al. (2021)	✓		-	Makespan					✓		Solution method: Six heuristic algorithms/IG

Table 3 (continued)

References	Distribution network type		Model	Objective	Category of solution methods			Comments
	Central- owned- ownership	Virtual alliance			Approximate	Exact	Metaheuristic	
Wang et al. (2020)	✓		✓	-	✓			Objectives: minimizing makespan and energy consumption Solution method: MOWSA
Hamzadayi (2020)	✓		✓	Makespan			✓	Solution method: Hybrid Benders decomposition
Jing et al. (2020)	✓		-	Total weighted E/T		✓		Considering due windows Solution method: IG
Jing et al. (2021)	✓		✓	Makespan		✓		Presenting a robust model Solution method: sIGA, sILS
Khare and Agrawal (2020)	✓		✓	Total tardiness		✓	✓	Solution method: Two heuristic algorithms, hybrid algorithm and an enhanced variant of IGA

**Table 3** (continued)

References	Distribution network type		Model	Objective	Category of solution methods			Comments
	Central-ized own-ership	Virtual alliance			Approximate	Exact	Metaheuristic	
Yang et al. (2020)	✓	–	–	Makespan	✓			Considering helper objective Solution method: An improved swarm intelligence optimization algorithm
References	Distribution network type		Model	Objective	Category of solution methods			Comments
	Central-ized own-ership	Virtual alliance			Approximate	Exact	Metaheuristic	
Liu (2020)	✓	–	–	Total flow time	✓			Solution method: 20 heuristic algorithms
Ali (2020)	✓	✓	✓	Makespan	✓		✓	Solution method: Construction heuristic and TS
Mao et al. (2021)	✓	–	–	Makespan	✓			Considering preventive maintenance operation Solution method: An effective multi-start IGA

**Table 3** (continued)

References	Distribution network type		Model	Objective	Category of solution methods			Comments
	Central- owned ownership	Virtual alliance			Approximate	Exact	Metaheuristic	
Rifai et al. (2021)	✓		-	-	✓			Objectives: minimizing the makespan, production cost, and tardiness Solution method: MOALNS
Baysal et al. (2021)	✓		-	Makespan		✓		Solution method: An artificial bee colony algorithm
Meng and Pan (2021)	✓		-	Makespan		✓		Considering lot-streaming and SDSST Solution method: NEABC
Ali et al. (2021)	✓		✓	Total completion time		✓		Solution method: TS
Li et al. (2021b)	✓		✓	Total flow time		✓		Considering mixed no-idle constraints Solution method: AIG
Li et al. (2021c)	✓		-	Makespan		✓		Considering the heterogeneous factories Solution method: DABC

**Table 3** (continued)

References	Distribution network type		Model	Objective		Category of solution methods			Comments		
	Central- owned ownership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic	Hybrid
Isguder and Hamzaday (2021)	✓		✓	Makespan		✓				✓	Solution method: Benders decomposition algorithms/ hybrid algorithm
Ying and Lin (2018)	✓		✓	Makespan			✓				Hybrid flowshop production environment
Li et al. (2020)	✓		✓	Makespan			✓				Solution method: SIG
Cai et al. (2020)	✓		-	-	✓						Considering SDST
											Solution method: DABC
											Objectives: minimizing makespan and maximize the total agreement index
											Considering SDST
											Solution method: CVS
Cai et al. (2020a)	✓		-	Makespan			✓				Presentation of a lower bound
											Solution method: DSFLA



**Table 3** (continued)

References	Distribution network type		Model	Objective		Category of solution methods			Comments	
	Central- ized own- ership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic
Cai et al. (2020b)	✓		-		-	✓				Considering SDST Objectives: minimizing total tardiness and makespan Solution method: MQSFLA
Wang and Li (2020)	✓		-		-		✓			Objectives: mini- mizing makespan and fuzzy total energy consump- tion, maximizing total agreement index Solution method: SFLA-CMSS

**Table 3** (continued)

References	Distribution network	Model	Objective		Category of solution methods			Comments
			Single objective	Multi-objective	Approximate	Exact	Metaheuristic	
Lei and wang (2020)	Central-ized own-ership	-	-	✓	✓			Considering SDST Two-stage hybrid flowshop environment Objectives: Minimizing makespan and the number of tardy jobs Solution method: A shuffled frog-leaping algorithm with memplex grouping
Shao et al. (2020c)		✓	Makespan			✓	✓	Solution method: A heuristics and multi-neighborhood IGA
Cai and Lei (2021)		✓	-	✓		✓		Objectives: minimizing fuzzy makespan and fuzzy total energy consumption, maximizing total agreement index Solution method: CSFLA

**Table 3** (continued)

References	Distribution network		Model	Objective	Category of solution methods				Comments		
	Central- owned ownership	Virtual alliance			Single objective	Multi-objective	Approximate	Exact		Metaheuristic	Heuristic
Wang and Wang (2020)	✓		-	Makespan			✓				Solution method: A memetic algorithm
Shao et al. (2021b)	✓		-	-	✓			✓			Objectives: minimizing makespan, total weighted E/T and total workload Solution method: An evolutionary algorithm based on multiple neighborhoods local search
Wu and Xia (2021)	✓		✓	Makespan				✓			Solution method: Fruit fly optimization method

between distribution plants in different geographic regions. In another research, Jia et al. (2003) proposed a modified GA with a two-step encoding method. To evaluate the performance of the proposed algorithm, they compared the GA results with the algorithm proposed by Muth et al. (1963). Chan et al. (2005) studied the problem of Jia et al. (2003) and, to solve it, they proposed a GA with dominant genes. Furthermore, Jia et al. (2007) proposed an integrated genetic algorithm-Gantt chart. Moon and Seo (2005) proposed a mathematical model and an evolutionary algorithm for solving this problem considering precedence constraints, flexible sequences, and alternative machines. The objective of this problem is to minimize the makespan. Liu et al. (2006) addressed the scheduling problems in a hybrid distributed manufacturing execution system. To solve this problem in the dynamic state, they proposed an approach based on a GA, multi-agent method, multi-closed loop control, and user cooperation structure. Moon et al. considered the multi-factory scheduling problem in a job shop environment. To minimize the makespan, they used topology sorting to generate a set of operations sequences and developed an evolutionary search approach to find feasible solutions. Wang et al. (2006) studied the distributed scheduling problem in a dynamic job shop production environment to minimize the production costs considering job deadlines. The authors developed a GA that was improved by iterative algorithms.

Naderi and Azab (2014) proposed two MIP models for distributed job shop scheduling problems. They solved small-size instances by CPLEX and solve medium and large-size instances by three heuristic algorithms and three greedy heuristics. In another paper, Naderi and Azab (2015) proposed a MIP model with the objective of minimizing the makespan. To solve the problem, they developed a greedy algorithm and simulated annealing algorithm, which improves by a local search. Chaouch et al. (2017) proposed three algorithms, namely modified ant colony optimization (MACO), ant system (AS), and ant colony system (ACS) for distributed job shop scheduling problem. The results of this paper showed that the MACO algorithm has better performance than the other two algorithms. Xia et al. (2019) developed a multi-objective model to minimize the makespan and total energy consumption. To solve this problem, they proposed a multi-objective artificial bee colony algorithm (MOABC). Lohmer et al. (2020) developed a mathematical model with the objective of the due date for this problem. Also, they proposed an adapted greedy heuristics and a GA to solve a large problem. Şahman (2021) proposed a hybrid algorithm based on the discrete spotted hyena optimizer (DSHO) and a greedy heuristic approach to solve the distributed job shop scheduling problem with the objective of minimizing the makespan. Jiang et al. (2020) studied this problem to minimize makespan and energy consumption. They proposed an effective modified multi-objective evolutionary algorithm with decomposition method (MMOEA/D) to solve the problem.

The flexible job shop scheduling problem is more complicated than the job shop problem. This problem in a distributed environment has attracted the attention of a number of researchers. For the first time, this problem was studied by Chan et al. (2006). They developed a MIP model with the objective of minimizing the makespan. Also, because of the complexity of the studied problem, they proposed a method based on the GA. In the proposed approach, the idea of dominant genes was used to identify and save the best chromosomes in the next generation. Liu et al. (2014) proposed a mathematical model and a GA for the distributed flexible job-shop scheduling problems to minimize the makespan. They used the real data of a Taiwanese fastener manufacturer to validate the proposed algorithm. To solve the distributed scheduling problem in the flexible job shop environment, Wu et al. (2017) proposed a GA. In the proposed algorithm, they used a new representation method for solution encoding. Chang and Liu (2017) proposed a hybrid GA for distributed

flexible job shop scheduling problem with the objective of minimizing the makespan. To solve this problem, Li et al. (2018) proposed a hybrid Pareto-based tabu search algorithm (HPTSA). To minimize the makespan, maximum workload, total job volume, and the sum of the E/T, they proposed a hybrid Pareto-based tabu search algorithm (HPTSA). Marzouki et al. (2018) proposed a CRO algorithm to solve the distributed flexible job shop scheduling problem. Lu et al. (2018) studied the flexible job shop problem in a distributed environment. Due to the complexity of the problem, they proposed a genetic-based algorithm. To a similar problem, Wu and Liu (2018) presented a mathematical model and an improved differential evolution simulated annealing algorithm (IDESAA) to minimize the makespan. Ziaee (2014) proposed a heuristic algorithm based on a constructive procedure to solve the distributed flexible job shop problem. Wu et al. (2019) developed a multi-objective mixed-integer linear programming model for the distributed assembly flexible job shop problem. To minimize the E/T and total production cost, they proposed a simulated annealing algorithm improved by crossover and mutation operators. Luo et al. (2020) studied the distributed flexible job shop scheduling problem. They assumed the operations of a job could not be transferred between different factories. To solve the problem, they proposed an efficient memetic algorithm (EMA). Mahmoodjanloo et al. (2020) studied the distributed flexible job shop scheduling problem in the dynamic environment. They developed two mathematical models for the static and the dynamic states with the objective of minimizing the total cost. They used a physical cyber system to obtain real-time data. To minimize the makespan, Meng et al. (2020a) developed four different MIP models in the distributed flexible job shop scheduling problem. In another paper, Meng et al. (2020b) developed a novel MIP model with the objective of minimizing energy consumption. Also, to solve large-size instances, they proposed a hybrid algorithm based on the shuffled frog-leaping algorithm. Du et al. (2021) considered the crane transportation in the distributed flexible job shop scheduling problem. The authors developed a MIP model to minimize makespan and total energy consumption. To solve the problem, based on the estimation of distribution algorithm and variable neighborhood search, they proposed a hybrid algorithm. Xu et al. (2021) formulated a mathematical model for distributed flexible job shop scheduling problem with the objectives of minimizing makespan, costs, quality, and carbon emission. They presented a fuzzy analytical hierarchy process and a hybrid genetic algorithm and tabu search to solve this multi-objective problem. The papers of this section are summarized in Table 4.

## 4 Research survey results

The purpose of this section is to analyze the reviewed papers in terms of their shop scheduling environment, having single or multiple objective functions, solution methods used, and their type of production network ownership in order to identify existing research gaps and provide suggestions for researchers.

In this paper, a total of 110 papers from the past eleven years have been reviewed. The distribution of sources of these papers is presented graphically in Fig. 1. As shown in Fig. 2, due to the practical nature of the problem, the multi-factory production scheduling problems have gained considerable attention in the last decade and the number of researches in this field is quite increasing.

Figure 3 classifies the reviewed papers according to their objective functions. As is clear from this analysis, among 110 papers, 75% (83 papers) have addressed single objective

**Table 4** Multi-factory scheduling with job shop production environment

References	Distribution network type		Model	Objective	Category of solution methods			Comments
	Central- owned ownership	Virtual alliance			Approximate	Exact	Metaheuristic	
Naderi and Azab (2014)	✓		✓	Makespan			✓	Proposing MIP models based on sequence and sequence variables
Naderi and Azab (2015)	✓		✓	Makespan		✓		Proposing methods for algorithm improvement Solution method: A greedy algorithm/ SA
Chaouch et al. (2017)	✓		–	Makespan		✓		Solution method: MACO/AS/ACS
Xia et al. (2019)	✓		✓	–	✓	✓		Objectives: minimize the makespan and total energy consumption Solution method: MOABC
Lohmer et al. (2020)	✓		✓	Due date		✓		Solution method: An adapted greedy heuristics / GA
Şahman (2021)	✓		–	Makespan			✓	Solution method: Hybrid algorithm

**Table 4** (continued)

References	Distribution network type		Model	Objective		Category of solution methods			Comments	
	Central- owned ownership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic
Jiang et al. (2020)	✓		✓	-		✓				Objectives: minimize the makespan and energy consumption Solution method: MMOEA/D
Liu et al. (2014)	✓		✓	Makespan			✓			Solution method: GA
Wu et al. (2017)	✓		-	Makespan			✓			Presenting a novel method for solution representation Solution method: GA
Chang and Liu (2017)	✓		-	Makespan					✓	Solution method: HGA
Li et al. (2018)	✓		-	-	✓				✓	Objectives: minimize the makespan, minimize the maximum workload, minimize the total job volume, and minimize E/T Solution method: HPTSA

**Table 4** (continued)

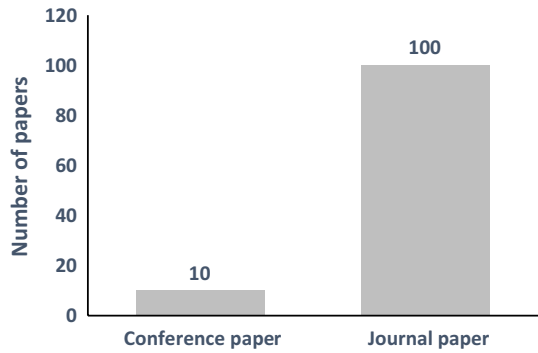
References	Distribution network type		Model	Objective		Category of solution methods			Comments	
	Central- owned ownership	Virtual alliance		Single objective	Multi-objective	Approximate	Exact	Metaheuristic		Heuristic
Marzouki et al. (2018)	✓		–	Makespan		✓				Solution method: CRO
Lu et al. (2018)	✓		–	Makespan		✓				Solution method: GA-JS
Wu and Liu (2018)	✓		✓	Makespan		✓				Solution method: IDESAA
Ziaee (2014)	✓		–	Makespan				✓		Solution method: Heuristic algo- rithm
Wu et al. (2019)	✓		✓	–	✓					Objectives: mini- mize the E/T and total costs
Luo et al. (2020)	✓		✓	–	✓					Solution method: An improved simulated anneal- ing algorithm
						✓				Objectives: minimize the makespan, maxi- mum workload of factories, and total energy consumption
										Solution method: EMA



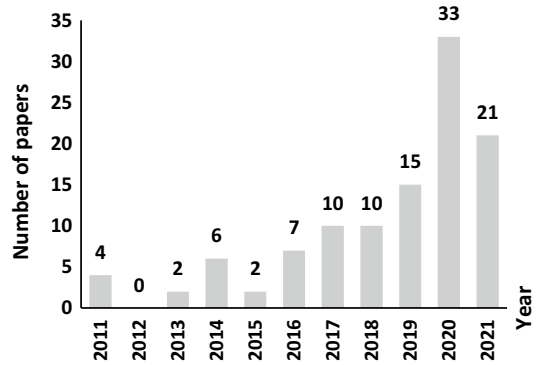
Table 4 (continued)

References	Distribution network type		Model	Objective	Category of solution methods			Comments
	Central- owned own- ership	Virtual alliance			Approximate	Exact	Metaheuristic	
Mahmoodjanloo et al. (2020)	✓		✓	The total cost				Considering the dynamic state
Meng et al. (2020a)	✓		✓	Makespan				Proposing four models
Meng et al. (2020b)	✓		✓	Energy consumption			✓	Solution method: Hybrid algorithm
Du et al. (2021)	✓		✓	-		✓		Objectives: minimize the makespan and total energy consumption
Xu et al. (2021)	✓		✓	-		✓		Objectives: makespan, costs, quality, and carbon emission

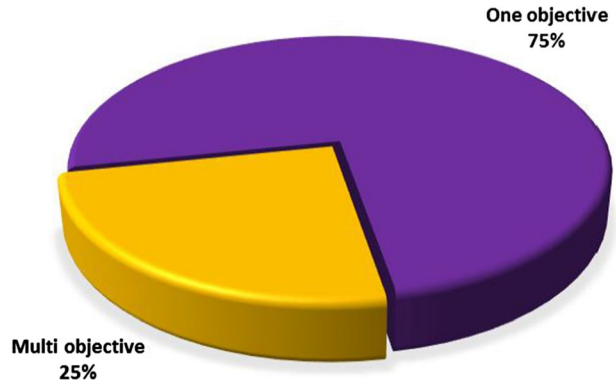
**Fig. 1** Source distribution of reference papers



**Fig. 2** Number of publications per year



**Fig. 3** Distribution of papers according to the number of objective functions



problems and just 25% of them (27 papers) have been dedicated to multi-objective problems. Furthermore, Fig. 4 reveals that 74% of the single objective multi-factory production scheduling problem papers consider minimizing the makespan as a widely used objective function in the multi-factory production scheduling problems. As shown in Fig. 5, most of the published papers (62%) considered flowshop production environment and few papers addressed other production environments (*i.e.*, parallel machines, job shop, and single machine). Furthermore, no research has been done on multi-factor scheduling in open shop

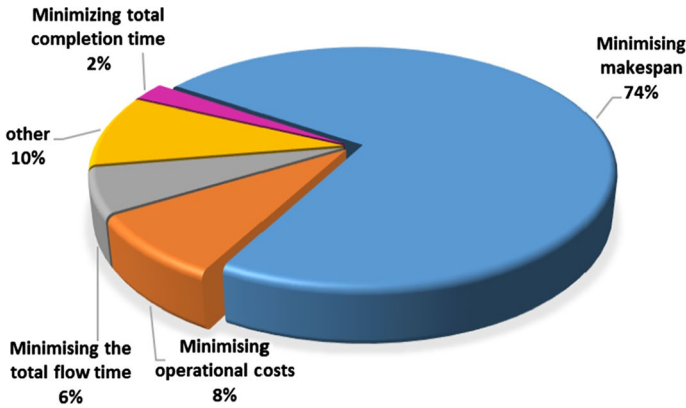


Fig. 4 Distribution of papers according to the objective functions

Fig. 5 Distribution of papers according to the production environment

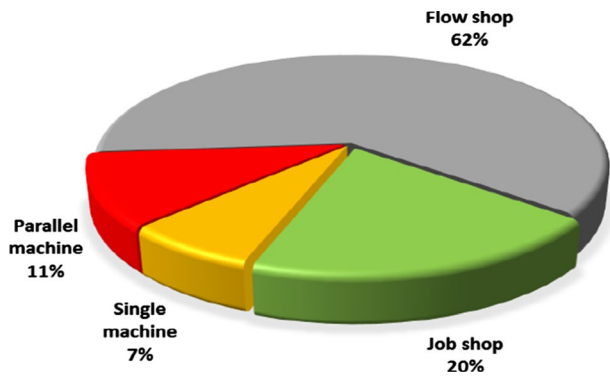
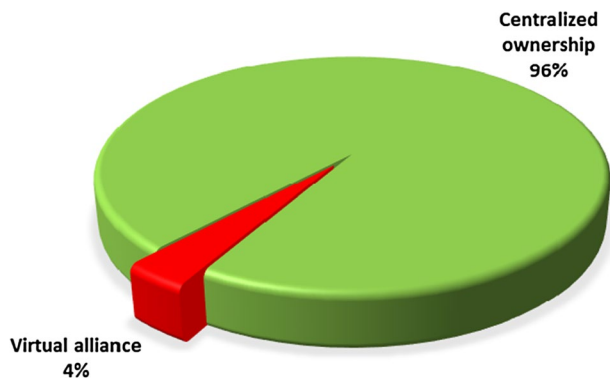


Fig. 6 Distribution of papers according to the production network structure



environments. The results of Fig. 6 indicate that in 96% of the published papers, the factories are managed by a central unit, while only 4% of the papers consider the production network as a virtual alliance. In this condition, factories are working together to create a virtual production network. In fact, production networks with the virtual alliances provide

**Table 5** Frequency of solving techniques

Solving techniques	Total number
Approximate algorithm	3
Exact method	3
Metaheuristic algorithm	85
Heuristic algorithm	17
Hybrid algorithm	17

a highly permeable and flexible structure, with very simple relationships and very low input and output constraints. In this production network, the factories can achieve more benefits than independent production.

According to studies on the published papers, a few numbers of resources have focused on communications between factories. Communications between factories improve interoperability between subsystems in a distributed model. This problem can be done by smartening the production system. Also, the number of studies that have considered the possibility of jobs transferring between factories in the distributed scheduling model has been very small. Obviously, not considering this issue will cause the multi-factory problem to become scheduling of several independent factories, and this leads to reduce the inherent attractiveness of the distributed scheduling problem and its complexity. Almost all of the research uses parallel factory structures, while series structure, as well as hybrid series-parallel modes in the form of integrated scheduling in the supply chain management, can improve system performance.

The solving techniques in this problem are also classified into five major categories (i.e., approximate algorithm, exact method, metaheuristic algorithm, heuristic algorithm, and hybrid algorithm). The number of studies in each technique is shown in Table 5.

As it is clear in this section, the largest portion of the proposed algorithms is related to metaheuristic, heuristic, and hybrid algorithms, which due to the complex nature of these problems, achieving these results has not been far from the mind. In this regard, the metaheuristic algorithms have been used 85 times in papers, while the approximate algorithms and exact methods have been used only three times.

## 5 Conclusions and emerging research fields

Due to the importance of the multi-factory production scheduling problem in the real world and industry, this research provided a review of this scheduling problem. After classification of publications based on shop environments, the multi-factory production scheduling in the single machine, parallel machines, flow shop, and job shop were reviewed between 2011 and 2021. Based on the analysis of reviewed papers, the emerging research fields are as follows:

The study in parallel machines, job shop and single machine production environments are appropriate topics for future research. In this regard, considering the open shop environment is especially recommended. Considering the virtual alliance production network in the different production environments is recommended. On this subject, integrating Industry 4.0 in manufacturing systems provides the advantages of real-time tracking and monitoring of the entities (Huang et al. 2019). In Industry 4.0, manufacturing systems are updated at a smart level, and the integration of new technologies of information and

communication is done using tools such as radio-frequency identification (RFID), big data, IoT, etc. Since in this generation of industry decisions are made faster, it is suggested that the most important features of Industry 4.0, such as participation, information sharing, flexibility, real-time data, and being online, be used in the multi-factory scheduling problems. Another common fault that occurs accidentally in smart factories is the failure of machines. In order to increase the system tolerance against failures, using the concept of reliability in the Industry 4.0 environment is suggested. It is also suggested that communication between factories be considered in the multi-factory scheduling problem in order to make it smarter, more practical, and more logical. In most researches, it is assumed that buffers between every two subsequent factories in a series structure have infinite capacity.

In recent years with the advent of just-in-time (JIT) systems, scheduling problems with JIT-related objective functions have become more operational. Therefore, the study of distributed JIT scheduling is suggested. Random events in the real world include the arrival of new jobs, failure of machines, changes to the due date, new orders, cancellation of orders, and delays in operations. Therefore, considering these events in multi-factory scheduling is suggested as future research. The study of multi-objective multi-factory production scheduling is another interesting topic for researchers. It is suggested that researchers consider environmental-related objective functions as well as the social responsibility of factories. For example, defining objective functions related to environmental issues such as reducing pollutants, efficient use of energy in scheduling, and reducing noise in the production process, are our other suggestions for future studies. Specifically, the study of distributed energy-efficient scheduling is suggested to those interested in this field.

As shown in the results, most papers have been using metaheuristic and heuristic algorithms. In the future, applying less frequent methods such as matheuristics, decomposition-based methods, and approximate algorithms are suggested. In particular, the use of decomposition methods is highly recommended due to the structure that exists in multi-factory scheduling problems. To use these methods, by decomposing the problem into assigning the jobs to the appropriate factory and scheduling the assigned jobs in the factory, researchers can use methods such as Benders decomposition, branch, and cut and, etc. In most papers, it is assumed that machines are constantly available. Therefore, it is suggested that constraints of the unavailability of machines be studied. Furthermore, integrating other supply chain decisions with the multi-factory scheduling problem is a new topic in the field. As an example, simultaneous consideration of the distribution problem with the multi-factory scheduling problem and integration of the classical vehicle routing problems in the production network scheduling is very attractive.

Due to the conflicting interests of members in virtual alliances, it inadvertently creates issues such as simultaneous cooperation and competition between the partners in the production network. Addressing such issues and using game theory topics is another future suggestion for this field. One important feature in multi-factory scheduling is the possibility of jobs transferring between factories. Considering the transportation time of jobs among factories is another suggestion. Obviously, in the real world, the number of vehicles is not unlimited, nor are they exactly the same. Adding hypotheses of vehicle heterogeneity in the movement of jobs as well as constraints on the number of transport fleets could be used in future research. Considering the real conditions in the problem, such as dynamic scheduling and scheduling in conditions of uncertainty such as fuzzy scheduling and stochastic/robust scheduling is our suggestion in this review. Our latest and perhaps less relevant suggestion for researchers is to use the concepts of multi-agent scheduling in scheduling other systems. For example, in health systems, and especially in operating room scheduling, considering hospitals as agents can be a great application of distributed scheduling. In such

cases, the objective function can be the participation of several independent hospitals in a hospital network with a virtual alliance to reduce casualties in emergency patients.

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