Current Situation and Development of Advanced Planning and Scheduling System Based on Group Optimization Algorithm in Discrete Industry

Miao Wang, Yuhua Huang, Jindong Zhang *
College of Computer Science and Technology, Jilin University, Changchun, China
* Corresponding Author Email: zhangjindong_100@163.com

Abstract. Discrete industry, especially job shop scheduling, has always been the key industry of Advanced Planning and Scheduling system (APS) system application. Based on Particle Swarm optimization (PSO), this paper introduces the Group swarm optimization algorithm, expounds the relevant theory and development status of APS, introduces the application of Particle Swarm optimization and Artificial Bee Colony optimization algorithm in APS system, and analyzes the performance and efficiency of the two algorithms. Finally, it predicts the future development trend of APS: the core algorithm will adopt a variety of hybrid algorithms, and the data flow will be combined with ERP / MES system.

Keywords: APS, PSO, Group optimization algorithm, Advanced planning and scheduling.

1. Overview

With the rapid development of science and technology, how to formulate production plans according to the diverse and changing needs of users is becoming a new problem. In view of this new situation of discretization and intelligence, Advanced Planning and Scheduling system (APS) has gradually emerged and become a new research object of many scholars. The most important core of APS system is algorithm. The quality of the algorithm determines the efficiency of the system. Since the beginning of APS system’s study, Group swarm optimization algorithm and Genetic algorithm (GA) have been widely used, and more than 60% of publications are related to these two algorithms. It aims to introduce how Group swarm optimization algorithm has been applied to APS system in recent five years. The second section introduces the development process of Group swarm optimization algorithm. The third section introduces the relevant theories and research status of APS system. The fourth section expounds the application of the latest derived group optimization algorithm in APS system, and the fifth section roughly looks forward to two development directions of APS: the mixing of multiple algorithms and the combination of ERP / MES system.

2. Theories and research status of group optimization algorithm

Group swarm optimization algorithm is one of the typical meta heuristic algorithms, which usually comes from the metaphor of typical biological processes or interactions. These processes can range from ecological interactions between organisms that promote the survival of the fittest to the behavior of birds looking for food sources. Based on the concept of multiple agents, bees, birds even fish cooperate to search for possible food sources or routes. Particle Swarm optimization (PSO) and Ant Colony optimization (ACO) are traditional algorithms that attracted extensive research interests in the early stage, which have recognized industrial influence in problem-solving ability and robustness.

Group swarm optimization algorithm is based on PSO, which is inspired by the movement of a flock of birds or a flock of fish. In PSO, the candidate solutions are used as the particles to explore the solution space, find the optimal solution according to the local optimal and global optimal conditions, and use the speed of the particle moving in the search space to complete the development of the current solution to the optimal solution. The specific flow chart of PSO algorithm is shown in Fig 1.
In the past three decades, the research on the construction and application of Group swarm optimization algorithm has solved a wide range of real-world optimization problems as a practical solution, and has made great development, such as many complex and NP-hard problems. However, Group swarm optimization algorithm is inspired by the intelligent behavior of animal groups and has many classifications, so no algorithm can be widely used in all problems. It can only choose the appropriate algorithm to solve the current problem, which has low practicability.

3. APS related theories and research status

APS is known as the supply chain optimization engine. It is an intelligent planning and scheduling tool based on supply chain management and constraint theory. It includes many mathematical models, optimizing ways and simulation technologies. Its outstanding advantage is to regenerate the scheduling plan based on constraints in real time, and even provide alarm function in case of emergencies. During the operation of the system, APS is constrained by the resources and capacity inside and outside the production workshop (materials, equipment, customer needs, transportation, deadline, etc.), implements complex and precise algorithms, carries out scheduling calculation and efficiency analysis, and selects the best scheme (under current conditions) from a large number of alternatives, so as to guide the enterprise in personnel allocation and resource management.

The problems solved by APS system can be simply understood as Job Shop Scheduling Problem (JSSP), that is, according to the known schedule in the workshop (the order of processing jobs through machines), taking the limited period and limited resources as constraints, so as to optimize the specified design standards as the goal, determine the processing sequence and time of workpieces on relevant equipment, and maximize the workshop performance and enterprise interests. However, the actual scheduling situation is much more complex than JSSP problems. For example, APS has the characteristics of real-time and high responsiveness. It can respond reasonably according to emergencies (such as order insertion, order cancellation and machine failure), and replan the production plan to meet the needs of users. In addition to scheduling, it is another difficulty in the implementation of APS system. A specific JSSP model including n workpieces and m machines can be described in Fig 2.
The development of APS is based on constraint theory, operations research, computer science, industrial engineering, production and operation management, artificial intelligence, decision support system, logistics management, management science and other management research results. The application of APS has become one of the key factors for most enterprises to win the competition in the West. Many of the world's top 500 enterprises (such as IBM, HP, Intel, Motorola, etc.) have implemented supply chain optimization models and production operation optimization scheduling models with optimization technologies such as operations research as the core. Running these optimization models every day has become an integral part of their daily management. However, APS system cannot directly collect all kinds of information on the production site, nor can it automatically transform the miscellaneous product demand information and constraints into the data required for modeling. Therefore, although APS system is widely studied at this stage, its utilization rate and efficiency are not high in China.

4. Several introductions of APS system based on group optimization algorithm

4.1. APS based on Particle Swarm optimization

In 2020, Haojie Ding and Xingsheng Gu proposed a rumor PSO algorithm based on a new coding method to solve the Flexible Job Shop Scheduling Problem (FJSP). Different from the traditional PSO, each particle of the rumor PSO obtains significant information by comparing the position information of several neighborhood particles, rather than directly obtaining the global optimal position information. The number of neighborhood particles is defined as $T$. The improved PSO realizes a novel coding scheme by relying on two carefully designed data structures: operation data structure and machine data structure. The operation list is realized by using the linked list structure, that is, the position of a particle corresponds to an operation list, which is filled with all necessary data. The total number of nodes in the operation list is equal to the sum of all operations, which is scale defined as $s$. The decoding scheme adopts the general decoding method. Firstly, according to the test set, the original operation list is generated by coding, and the Particle Swarm optimization is initialized. The detailed flow of the algorithm is shown in Fig 3.

![Figure 3. Detailed flow of the improved PSO](image-url)
Compared with the PSO + rule of Girish and Jawahar (2009a), PSO+ TS of Li et al. (2010), and MATPSO of Henchiri and Ennigrou (2013), the algorithm shows that 4 results in 10 test sets are expressed as optimal solutions, and the average error between the other 6 suboptimal solutions and their optimal solutions is no more than 10%, which shows its excellent performance.

4.2. APS based on Artificial Bee Colony algorithm

Artificial Bee Colony algorithm (ABC) is widely used in FJSP problem. Traditional Artificial Bee Colony is divided into hired bee, bystander bee and reconnaissance bee. Hiring bees are responsible for finding the source of nectar and transmitting the information to the onlookers; Bystander bees select the flower nectar source according to the richness information of the flower nectar source transmitted by the hired bee, and looks for new flower nectar sources near this flower nectar source to accelerate the convergence of the algorithm. Reconnaissance bees randomly search for new nectar sources to help the algorithm jump out of local optimization. The location of the nectar source corresponds to the solution of the problem, and the amount of nectar in the nectar source is related to the fitness of the solution. In 2020, Yibing Li and Weixing Huang realized a workshop scheduling system based on multi-objective Improved Artificial Bee Colony algorithm (IABC). According to the three subproblems of job shop scheduling: job scheduling, machine layout and speed allocation, the algorithm designs three vectors: the operation sequence vector (OV) composed of the operation sequence of all jobs, the machine allocation vector (MV) composed of the sequence of processing machines arranged in each operation process of each job, and the speed allocation vector (SV) of the corresponding machine speed after the processing machines are arranged in MV. Decoding is the inverse process of encoding.

The implementation process of IABC is similar to most Group optimization algorithms. Firstly, the population is initialized, and the combination of random generation and strategy selection is adopted to randomly generate the index of 10% of OV, and the other 90% use strategy selection. Then hiring bees perform the functions of operation sequence crossover, machine allocation mutation and speed allocation mutation. Bystander bees choose the corresponding hired bees through the selection strategy, and decide whether to recruit or give up the corresponding food source. Reconnaissance bees explore new sources of food near the hive. Different from the performance comparison standard of improved PSO algorithm, IABC uses the concept of Pareto advantage to determine which production scheme is better. Experiments show that compared with the data results MOPSO of Wang B and Xie H (2016), MODE of Warisa W and Voratas K (2013), and NSGA-II of Wang B.et al. (2019), this algorithm has significant advantages in the comparison of three indicators: Inverted Generational Distance (IGD), Error Rate (ER) and the number of Non-dominated solutions (N), and has the best performance.

5. APS development trend

5.1. Hybrid algorithms become the mainstream

Although there are many options for APS scheduling algorithm, each algorithm has its own advantages and disadvantages. Taking PSO as an example, it has outstanding advantages such as fast convergence speed, easy implementation and robustness, but it lacks the balance ability of good exploration and utilization, and is easy to fall into a local optimal situation. In this case, PSO can combine the advantages of other algorithms to improve the performance, improve the global and local search ability, and then realize more functions. In recent ten years, the APS system with multiple algorithms has gradually become the mainstream, and the function of a single algorithm is slightly weak. In early 2022, Faisal Alkhatteeb and Bilal H. Abed-almgini proposed a cuckoo and simulated annealing (SA) hybrid algorithm, which combines Variable Neighborhood Search (VNS) and Lévy-flight method to better explore the search space, and uses the learning method based on fine English opposition to jump out of the local optimization before the abandonment step of CSA. This algorithm can not only converge faster to get the optimal solution, but also take less time, and has excellent
efficiency and performance. To realize a perfect APS system, it should not only be familiar with various algorithms, but also understand the advantages and disadvantages of algorithms, learn from each other, learn from each other, so as to produce a win-win or even multi win situation.

5.2. Combined with ERP / MES system

Although APS system can well plan various plans, the system itself cannot integrate data and cannot operate independently, so it must have basic data as support to build models and design constraints. Let APS extract basic modeling information such as production route, raw material supply, inventory and order from ERP to implement and plan optimization activities, and then import the optimal scheduling plan into ERP / MES system for operation. In this way, APS can be embedded into ERP system as ERP decision-making system. APS can complement and improve the ERP planning system and optimize the ERP decision-making system. APS can only be used in closed-loop system. ERP system is a complete feedback regulation closed-loop system. This integration method can not only optimize the ERP planning unit, but also does not affect other parts of ERP. The new system integrates the advantages of the two. Nowadays, ERP is widely used, and the need of APS is more and more. How to integrate APS and ERP / MES system, give full play to the advantages of the three systems, retain their respective functions and streamline the integration process will become a new exploration direction. However, it should be made clear that the core of APS system is algorithm, and the quality of algorithm determines the efficiency of APS. ERP system can only provide basic data as an information system, and the optimization of core algorithm needs further research.

6. Conclusion

In the past two decades, Group optimization algorithm has developed continuously, and APS system has been gradually popularized. As the core of APS performance, the algorithm has been also studied continuously. The two systems introduced in this paper have made breakthroughs in coding and decoding, and the experimental results are also satisfactory. Literature review shows that more and more researchers have proposed innovative algorithms, and continue to combine the latest technology (such as cloud) with APS system. APS system has more perfect functions, better efficiency and brighter development. However, due to the difficulties in decision-making, state identification and data diagnosis, the execution efficiency of APS system is low, and there is still a long way to go before it is widely used.

Acknowledgments

This work is supported by the Korea Foundation for Advanced Studies’ International Scholar Exchange Fellowship for the academic year of 2017-2018.

References


