A Production Scheduling Method for Flexible Flow Shops Based on Simulation Models

Jihong Yan*, Ph.D.
Professor in Industrial Engineering
Deputy Dean of School of Mechatronics Engineering
Head of intelligent Manufacturing Scientific Research Team
Harbin Institute of Technology
Harbin, China
jyan@hit.edu.cn

Weiyi Zhao, Bachelor
School of Mechatronics Engineering
Harbin Institute of Technology
Harbin, China
zhaoweiyi98@163.com

Abstract

In the context of Industry 4.0, the level of workshop production automation has been greatly improved. Flexible flow workshops that produce multiple varieties and small batches of products have rich resources and complex processing procedures, where are featured by many constraints for the production scheduling and varying practical procedure of the production. Traditional production scheduling research is mostly based on mathematical methods by simplifying the production model to a mathematical model and using algorithms to find the optimal solution. This method is not accurate enough to model the realistic production process in the workshop, which leads to inadequate guidance for actual production. This paper proposes an optimization production scheduling method based on simulation model and establishes a systematic simulation-based flow shop scheduling framework. It uses a database as a bridge to external optimization algorithms and internal simulation models, and realizes intelligent production scheduling and simulation through real-time interaction. This research is able to accurately reflect the processing logic of the actual flow shop, and the result of scheduling shows that the proposed method has more practical significance for guiding the actual production process.

Keywords
Production scheduling, Simulation model, Optimization method, Flexible flow shop.

1. Introduction

Flexible flow shop scheduling problem (FFSP) which is also known as hybrid flow shop scheduling problem (HFSP) was proposed by Salvador in 1973 based on the background of the petroleum industry (Salvador 1973). Compared with the original flow shop scheduling problem, the number of parallel machines increases leading to a range extension of feasible solutions for the scheduling problem and the complexity of the problem increases. The scheduling problem has always been one of focuses of manufacturing industry and it is essential for improving the competitiveness of manufacturing enterprises. The main contents of research on traditional scheduling problems are models and optimization algorithms.

The traditional methods of scheduling extract the production problems into a mathematical model and optimize the model through algorithms. Mixed integer linear programming (MILP) and mixed integer non-linear programming are widely applied to solve scheduling problems. Roslof et al. solved production scheduling and rescheduling problems based on the classic MILP algorithm (Roslöf et al.2001); Harjunkoski et al. proposed a decomposition strategy that using mathematical programming methods to solve large-scale scheduling problems. They decompose complex global optimization problems into easy-to-solve programs (Harjunkoski and Grossmann 2001); Shobrys et al. designed a large-scale mixed integer programming optimization model based on continuous and discrete time representations for production scheduling (Shobrys and White 2002).

With the continuous deepening of research, the production scheduling problem has gradually been proved to be an NP-hard problem and many optimization algorithms are developed to solve this problem. The meta-heuristic algorithm also called the intelligent algorithm is widely used and representative. Meta-heuristic algorithms include genetic algorithm, tabu search algorithm, simulated degradation algorithm and ant colony algorithm etc., among which the application of genetic algorithm is frequently researched. In 1985, Davis applied the genetic algorithm to the scheduling problem and applied the indirect coding based on the priority list to solve the scheduling problem (Davis 1985); In 1991, Nakano et al. first applied the genetic algorithm to the typical Job-shop problem (Nakano and Yamada 1991); Li et al. proposed partheno genetic algorithm to solve scheduling problems. It solves the problem of the algorithm's complex calculation and low efficiency in solving the Job-shop problem (Li 2013); Considering machine load balance and maximum completion time when initializing the population is a key step which improve the convergence speed of the algorithm (Zhang et al.2009). The research on optimization algorithms mostly focuses on reducing the iterative speed of the algorithm and enhancing the optimization ability of the algorithm. Tay et al. used genetic programming algorithm to solve the multi-objective flexible flow shop problem (Tay and Ho 2007). Bharti et al. developed two hybrid frameworks using hybrid particle swarm and hybrid genetic algorithms to solve multi-objective optimization scheduling problems respectively (Bharti and Jain 2020).

Faced with large-scale scheduling problems and the complex production situation, real-time scheduling is hard to be realized and the calculation speed is slow. In contrast, scheduling rules are easy to implement and respond to dynamic changes (Alexander et al.2013). Based on the above discussion, it is difficult for traditional research to restore all production conditions. Such methods are not accurate enough to model the realistic production process in the workshop, which leads to inadequate guidance for actual production. And the actual production situation is random, so it is difficult to achieve a complete restoration of the mathematical planning model.

Simulation Based Optimization (SBO) methods solve these problems effectively. The simulation approach provides process modules which can be adjusted with certain parameters by using data which easily obtainable in production process. SBO mainly includes two methods. The first is simulation for strategy verification, that is, the strategy input model drives the simulation operation to achieve production simulation. Simulation-based optimization methods determine how to allocate storage space for automated storage systems (Takahama et al.2002). Then the discrete simulation model which is employed to best describe the system and therefore to evaluate the system behavior over time. This simulation model permits to verify the feasibility of a given optimal planning proposed by a mixed integer programming model (Belil et al.2019). The second is the simulation output fitness value. The simulation result is used as the output value of the algorithm and the result of algorithm optimization as the input of the model. Daniel et al. used this method to solve the problem of supply chain design and scheduling (Daniel and Rajendran 2005). The simulation model in Plant Simulation is utilized and the build-in genetic algorithm of optimizing module is applied to optimize job-shop scheduling which assure the scientific decision (Xiang and Jian 2012).

The above researches have innovated and optimized the production scheduling problem from the perspective of model and algorithm, but has not formed a systematic method to realize the organic combination of model and intelligent algorithm. This paper proposes a simulation-based production scheduling method to realize the real-time interconnection and mutual restriction between models and algorithms. This method restores the actual production situation to the greatest extent and establishes a database as a bridge to connect simulation model and optimization algorithm. The model decodes and outputs the fitness value, and the improved GA completes the optimization. Finally, this paper designs a systematic method to solve the scheduling problem.

This paper proposes an optimization production scheduling method based on simulation model and establishes a systematic simulation-based flow shop scheduling framework. The section 2 describes the structure and content of the simulation model. The section 3 introduces the interconnection between model and algorithm that how the scheduling method comes to be systematization. Finally, this proposed method based on simulation model systematically integrates the algorithm and the model and realizes production scheduling.

2. Simulation model for Flexible Flow shop

Taking the multi-variety and small-batch product processing workshop - Workshop A as a case, the proposed method builds a production site simulation model which is divided into workshop execution module, workshop interaction module and workshop monitoring module. The model not only restores the layout of the machine tool at the production site but also realizes the real-time simulation of the shift system of the workshop personnel.

2.1 Workshop execution module

The workshop execution module is composed of two parts: the workshop entity and the logic method. There are 8 machine tools in workshop A. The number of processes for each product varies and the processing time for each process is determined. In the physical part of the workshop, the geographic locations of devices were restored in equal proportions and a production preparation area was set up in front of each device as a pre-processing buffer area.

The buffer area controls the time when the product enters the equipment and starts processing. The workshop simulation model highly restored the production site through the physical part of the workshop. And the visualization of the model is realized thus the operation of workers, products and equipment in the model is observed in real time. The module is shown in refure 1.

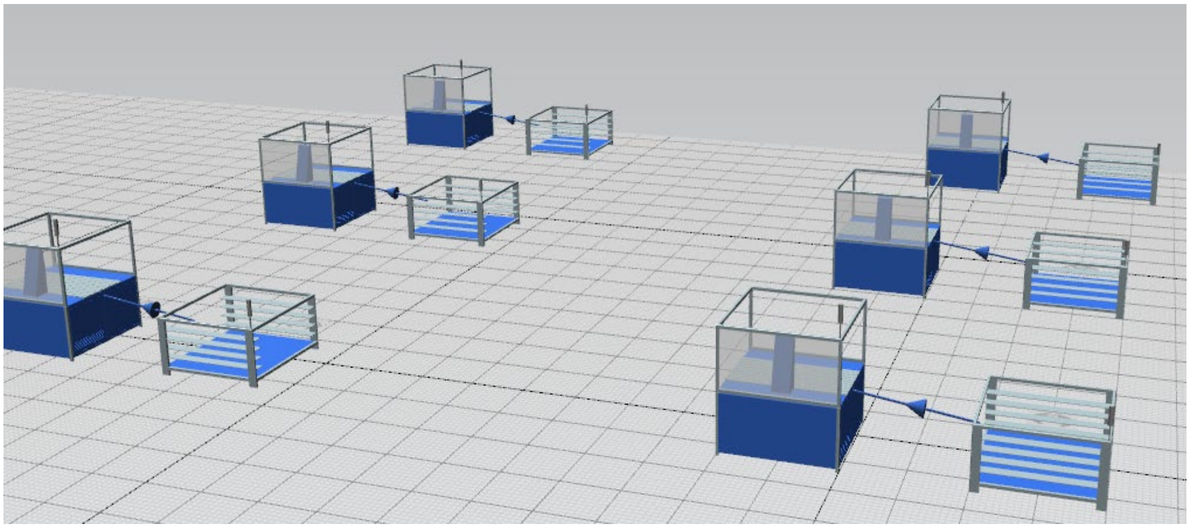

Figure 1. Workshop execution module

The logic method, as described in Figure 2, sets up the switch logic of the machine tool and the production preparation area. It also summarizes the processing information table of the product and the machine tool and sets the production shift information of the workshop personnel and equipment. Method logic blocks are used in the model for programming to control the distribution of product materials and the access switches of simulation modules such as machine tool equipment and the preparation area.

(1) Resource distribution station: All production materials are initially distributed by a fixed resource distribution station. The distribution station only has an export control program named Method-sourceexit.

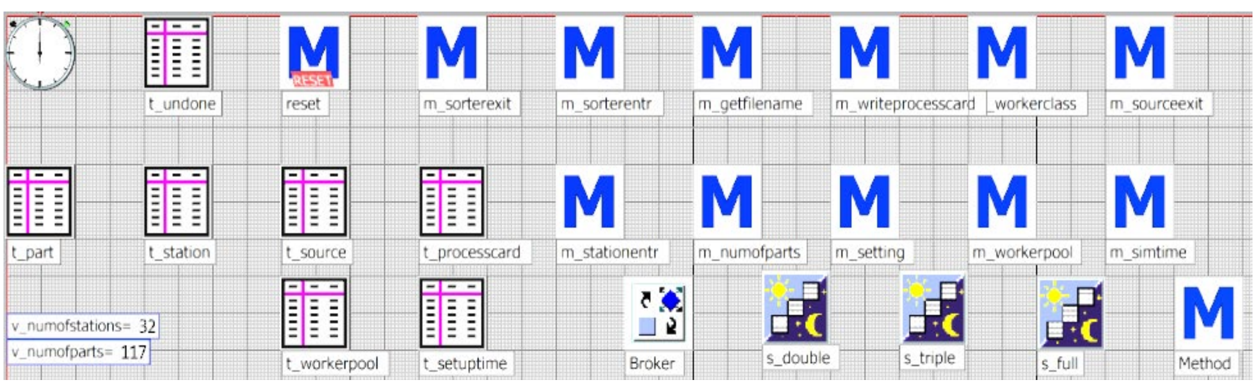

Figure 2. Logic method of model

This program is created to search for the station that each product needs to be transported and the processing time on it. Ensure that the processing materials reach the production preparation area of the corresponding equipment. The schematic diagram of it in the model is shown in Figure 3.

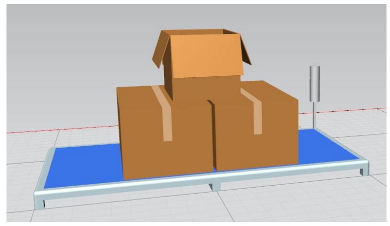

Figure 3. Resource distribution station

(2) Production preparation area: The production preparation area is used as a buffer for pre-processing resources. It has two control programs for this area's entrance and exit which named Method-sorterexit and Method-sorterentr respectively. And accesses pointer variables that analogy with the gateway switch are applied to determine the arrival of the material and the input of the resources to the equipment. This method controls the switch according to comparing the priority variable of the product entity with the corresponding completion number.

(3) Equipment processing area: The equipment processing area is a simulation of the machine tool. The failure rate, the utilization rate and the shift information are set to realize the restoration of the production site. The logic module named Method-stationentr is the control of the start time of the processing. It is the entry switch of the equipment processing area. This logic judges whether the machine tool currently completes the processing and writes the next procedure of the product corresponding to the machine tool and processing time. The above two parts (Production preparation area and Equipment processing area) are shown in Figure 4.

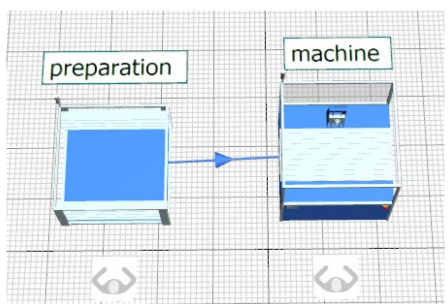

Figure 4. Production area

(4) Workers and shift system: The complete restoration of worker information and workshop production shift system is realized through the worker pool function and shift system setting module as shown in Figure 5. The workshop execution module is the main part of the simulation and logic of the model which builds the physical foundation of the model and applies the Method module to program and control the operation of the model. It is the logical basis of the simulation model.

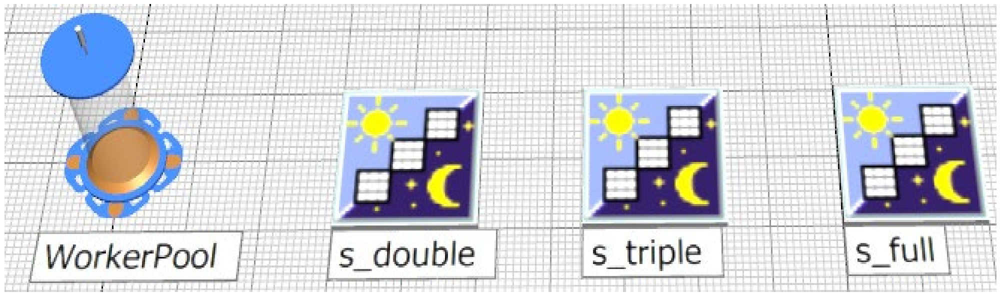

Figure 5. Workers' system

2.2 Interactive module

The workshop interactive module is the interactive processing part between the model and the environment. Specifically, it is divided into the Open Database Connectivity part and the algorithm setting and decoding part.

The data interaction part uses the built-in function module of the simulation software: ODBC (Open Database Connectivity) to realize the access of the model and reading to the MySQL database. It reads the algorithm iteration results stored in the database into the model and sets the initial parameters and output parameters of the algorithm. The fitness value is written to the database.

The decoding part is to initialize the algorithm parameters in the model. It decodes the algorithm optimization results and outputs the overall operation results of the scheduling model. Recording the fitness value corresponding to the optimization of each generation of the population is the necessary functions of this area. The interaction module is the window between the model and the environment which realizes the interaction between the model and the database and also completes the reprocessing of the algorithm optimization results by the model. It is the brain of the model. (see Figure 6)

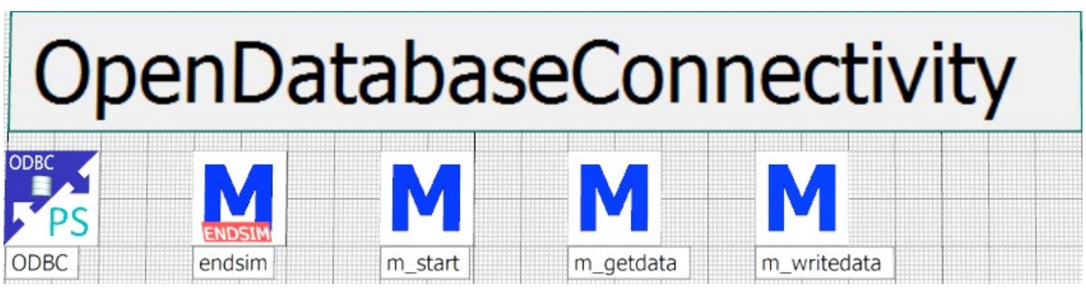

Figure 6. Interactive module

2.3 Monitoring control module

The workshop monitoring module realizes the mutual control and monitoring of the model and the algorithm which is equivalent to setting the simulation start switch to monitor the iterative process of the algorithm in real time. When the algorithm is optimized from generation to generation, the model can correspondingly complete the simulation of the results of each generation and output the corresponding Fitness value. This module is the control center of the model. The model is supposed to simulate and restore the optimization results of each generation by real-time monitoring of the algorithm iteration process and model simulation process.

3. Interconnection between Model and algorithm

3.1 Systematization of scheduling methods

According to the definition issued by the International Council on Systems Engineering in 2019: An engineered system is a system designed or adjusted to interact with the expected operating environment to achieve one or more expected purposes. The focus of current application research is establishing a systematic model that combining the actual production application. And it will integrate the scheduling rules, optimization algorithms and simulation models. Therefore, this method intends to realize the systematic integration of simulation models and optimization algorithms that reflect the scheduling rules.

This paper builds the interconnection bridge between the model and the algorithm by the establishment of MySQL database and systematically integrates the two independent parts. The genetic algorithm is written by Python statements to read and write the database. The algorithm also writes the optimization results of each generation to the database in real time. The model's monitoring module decodes its optimization results after the database is updated and completes real-time simulation. This way realizes the real-time interaction between the model and the algorithm; and it designs the systematic integration of the two parts and achieves the automation of scheduling optimization. The specific approach is shown in Figure 7.

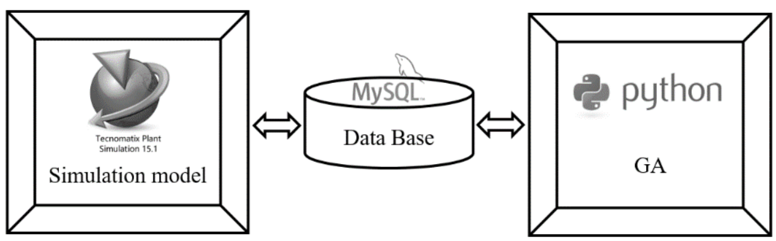

Figure 7. Systematization of scheduling

3.2 The ability for expressing the production of reality

The simulation-based optimization scheduling method described in this article can not only realize the analysis of the historical data of the production site to realize the rescheduling, but also complete the decision-making of future scheduling under the guidance of the production data. It achieves the greatest degree of restoration of the actual production through the integration of the model and the optimization algorithm. It has a strong practicality and a better practical guiding significance for the actual production than the mathematical planning model.

4. Conclusion

The proposed method is applied to re-schedule the monthly production of the flexible flow production workshop - Workshop A. The production time after scheduling has been shortened by comparing with the historical production time. The optimization effect directed actual production of the factory is significant. This proposed method based on simulation model realizes production scheduling and systematically integrates the algorithm and the model through database connection. It realizes the implementation simulation and interaction of scheduling strategy based on traditional SBO method.

Acknowledgements

This work was supported in part by the JCKY Project of China (#JCKY2019603C016).

References

Salvador, M.S., A Solution to a special class of flow shop scheduling problems. Proceedings of the 1973 Symposium on the Theory of Scheduling and Its Applications, vol. 83, no. 92, 1973.

Roslöf, J., Harjunkoski, I., Björkqvist, J., Karlsson, S., and Westerlund, T., An MILP-based reordering algorithm for complex industrial scheduling and rescheduling, *Computers and Chemical Engineering*, vol. 25, no. 4, 2001.

Harjunkoski, I., and Grossmann, I.E., A decomposition approach for the scheduling of a steel plant production, *Computers and Chemical Engineering*, vol. 25, no. 11, 2001.

Shobrys, D.E., and White, D.C., Planning, scheduling and control systems: why cannot they work together, *Computers and Chemical Engineering*, vol. 26, no. 2, 2002.

Davis, L,Job-shop scheduling with genetic algorithm, *Proceedings of the 1st International Conference on Genetic Algorithms and Their Application,* vol. 136, no. 140, 1985.

Nakano, R., and Yamada, T., Conventional genetic algorithm for job shop problems, *ICGA*, vol. 91, pp. 474-479, 1991.

Li, Y.X., Using partheno genetic algorithm to solve job shop scheduling problem, *Inner Mongolia Science Technology & Economy*, vol. 10, pp. 93-94, 2013.

Zhang, G.H., Gao, L., Li, P.G., and Zhang, C.Y., Improved Genetic Algorithm for the Flexible Job-shop Scheduling Problem, *Journal of Mechanical Engineering*, vol. 45, no. 07, pp.145-141, 2009.

Tay, J.C., and Ho, N.B., Evolving dispatching rules using genetic programming for solving multi-objective flexible job-shop problems, *Computers & Industrial Engineering*, vol. 54, no. 03, 2007.

Bharti, P., and Jain, S., Hybrid frameworks for flexible job shop scheduling, *The International Journal of Advanced Manufacturing Technology*, 2020.

Alexander, H., Herbert, J., and Klaus, A., Influence of dispatching rules on average production lead time for multi-stage production systems, *International journal of production economics*, vol. 144, no. 02, 2013.

Takahama, H., Nishi, T., Konishi, M., and Imai, J., A determination method of product allocation schedule for warehouse management, *SICE 2002. Proceedings of the 41st SICE Annual Conference. IEEE*, (2002).

Belil, S., Tchernev, N., and Kemmoé-Tchomté, S., Simulation based optimization decision support tool for production planning, *IFAC PapersOnLine*, vol. 52, no. 13, 2019.

Daniel, J.S.R., and Rajendran, C., A simulation-based genetic algorithm for inventory optimization in a serial supply chain, I*nternational Transactions in Operational Research*, vol. 12, no. 1, 2005.

Xiang, K.T., and Jian, W., The Simulation Optimization for Job-Shop Scheduling Based on Plant Simulation Using Genetic Algorithm, A*pplied Mechanics and Materials,* 2012.

Biography：

Jihong Yan is a professor (since 2005) in Industrial Engineering at Harbin Institute of Technology (HIT), she is also the deputy dean of School of Mechatronics Engineering and head of intelligent manufacturing scientific research team at HIT. She received her PhD from Harbin Institute of Technology. Then she joined Tsinghua University, the University of Wisconsin, and Pennsylvania State University as a postdoctoral researcher. Dr. Yan is the director of National High-end Equipment Manufacturing Virtual and Simulation Experiment Teaching Center, head of Research Oriented Teaching Innovation Team for High-end Equipment Manufacturing of the Ministry of Industry and Information Technology of China, vice chairman of Production System Special Committee of Chinese Mechanical Engineering Society, and chairman of Industrial Engineering Professional Committee of the Mechanical Engineering Society of Heilongjiang Province. Her main area of research is industrial big data, sustainable manufacturing, intelligent logistics and advanced maintenance of machinery. As a PI, Dr. Yan has worked on and accomplished 15 projects in intelligent manufacturing and sustainability related areas, funded by the NSF of China (NSFC), NSFNSFC joint-project funding, National key R&D plan project funding, National High-tech project funding, National "863" project funding, EU EPSRC project funding, High-tech funding from industries, and so on. She has authored and co-authored over 100 research papers and published 3 books, two papers were ranked ESI high cited articles. Currently there are 17 professors and engineers with her research team, the team dedicates to theoretical research and system implementation in the fields of intelligent operation optimization theory and methods of manufacturing systems, manufacturing IoT technologies and devices, and equipment health monitoring, etc.