Spatial Scheduling and Workforce Assignment Problem for Block Assembly of Hull Workshop

Wenmin Han[1, a *], Yonggang Qiang[2,b] Lulu Zhang[3,c] and Jun Wu[4,d]

[1] School of Economics and Management, Jiangsu University of Science and Technology, Zhenjiang, China

[2] School of Economics and Management, Jiangsu University of Science and Technology, Zhenjiang, China

[3] School of Economics and Management, Jiangsu University of Science and Technology, Zhenjiang, China

[4] School of Economics and Management, Jiangsu University of Science and Technology, Zhenjiang, China

[a] wlmh63@163.com, [b] 15052245662@163.com, [c] 1723852297@qq.com, [d] wujunjm@sina.com

*corresponding author

Keywords: Block Assembly; Spatial Scheduling; Workforce Assignment; The Average Maximal Free Rectangle Space Method

Abstract: For block assembly, spatial scheduling and workforce assignment are two important issues. Spatial scheduling is to decide the time and location place to assemble block, and workforce assignment is to assign working teams to the blocks. These two problems are considered at the same time, which not only achieves the efficient production of the hull workshop but also meets the requirements of the workforce's work balance. Based on this, a two-stage mixed scheduling algorithm is proposed. This algorithm uses a multi-layer coding genetic algorithm to obtain the optimal sequence of tasks and working team arrangement for processing in a certain period and then uses the average maximal free rectangle space strategy to obtain the collaborative scheduling solution of time organization, space organization, and operator.

Introduction

Ship production is a typical large complex product production, in the production process with strict time and space constraints, space organizations will affect the timing of production tasks, and efficient time organizations will request the form and dynamic adjustment of space organizations. At the same time, the workforce assignment will have an impact on the organization of space and time. Two decisions are therefore involved in the study of such issues: One is to determine the assembly time and location of the blocks (spatial scheduling problem), and the other is to implement the optimal job arrangement for the blocks (workforce assignment problem).

The spatial scheduling problem is mainly solved by two-dimensional placement method, three-dimensional bin packing method and two-stage scheduling method. The two-dimensional placement method is planned in a limited two-dimensional space according to the envelope rectangle of the product, which makes the utilization of the space higher. The three-dimensional bin packing problem is proposed based on the two-dimensional placement method. The third dimension is the time dimension, which gives time to space and realizes the coordinated consideration of space and time. However, the three-dimensional bin packing method is too difficult to solve the problem of large-scale block space scheduling. Therefore, relevant researchers proposed a two-stage scheduling method, using the idea of "dimensionality reduction" to simplify the complex scheduling process. Zhang and Chen[1] presented a two-stage approach to solve the spatial scheduling problem that arises in hull block assembly shops. In the first stage, the method reduces the number of

DOI: 10.38007/Proceedings.0001102 ISBN: 978-1-80052-007-3

unscheduled blocks, the second stage optimizes the scheduling and spatial allocation of blocks. Ge et al.[2] proposed a dynamic scheduling algorithm based on heuristic rules to solve the problems in ship spatial scheduling. The algorithm consists of two rules of batch processing and dynamic planning, and at the same time guarantees the punctuality of the block and site utilization. Zhang et al.[3] proposed a spatial scheduling method based on multi–rules. In this method, time and space similarity rule is proposed. All the unscheduled blocks in the same scheduling period are classified by using the time and space similarity rule. Then, these blocks are allocated into corresponding time slots. The layout of these blocks on working plate is then determined by means of the Best available point search method. Wang et al.[4] proposed a hierarchical nesting spatial scheduling algorithm for complex shape blocks production arrangement. Under this algorithm, the block spatial scheduling problem was divided into sequence optimization and position searching. Zhuo et al.[5] considered the dynamic space-constrained problem as two sequential decisions, namely rule-based dispatching and a static spatial configuration. Hu et al.[6] proposed a hybrid heuristic algorithm to solve block construction space scheduling problem. Firstly, Bottom-Left-Fill (BLF) process is introduced. Next, an initial solution is obtained by guiding the sorting process with corners. Then on the basis of the initial solution, the simulated annealing arithmetic (SA) is used to improve the solution by offering a possibility to accept worse neighbor solutions in order to escape from local optimum.

However, the spatial scheduling scheme obtained by the above method does not take into account the influence of the workforce. So that Zheng et al.[7] developed a mathematical model for block spatial scheduling, which based on the investigations of the characteristics of block shapes, the corresponding processing techniques, typical constraints and workload balance among working teams. Zheng et al.[8] developed a block spatial scheduling system and implemented it with real data from a large ship. Through the spatial scheduling system, visual results of daily block layouts and progress charts for all blocks can be easily obtained and according to different working teams, adjust the scheduling result above to get better workload balance. Tao et al.[9] proposed an approach that solves jointly the spatial scheduling problem and the workforce assignment problem. The objective is to improve the coordination among working teams and increase the productivity of assembly shops.

In these studies, each working team assumed the completion of all assignments for the target blocks. However, in combination with the actual investigation, it is found that due to the different number of operators' skills and processing ability, it is necessary to coordinate the assignment of working teams for each block process, and the different assignment schemes will lead to the change of the sequence and spatial position of the block operation in the hull workshop, which will affect the implementation of the scheduling scheme. Based on this, this paper aims at the actual production situation of the hull workshop in Zhenjiang shipyard, considering the constraints of time, space, working team and so on, to realize the parallel consideration of space scheduling and workforce assignment and to improve the efficiency of block assembly.

Modeling for the spatial scheduling-workforce assignment problem

(1) Decision variables

S_{jf}: the start time of the fth operation in the jth block;

C_{jf}: the completion time of the fth operation of the jth block;

C_j: the construction time of the jth block;

X_{ijf}: 1 when operation F_{jf} selects the ith working team, otherwise it is 0;

Y_{ijfk}: 1 if step F_{ijf} precedes step F_{ikf}, otherwise it is 0.

(2) Objective functions

Formulas (1) and (2) are expressed as two goals of the shortest total construction time[10,11] and maximum average space utilization[12,13] of the hull workshop.

$$F_1 = \min \sum_{j=1}^{n} \max\left(C_j\right) \tag{1}$$

$$F_2 = \max \frac{\sum_{j=1}^{N} \frac{\sum_{i=1}^{b_j} l_i \times w_i}{S}}{N} \tag{2}$$

(3) Time constraints

Formulas (3) and (4) represent the sequential constraints of the construction process in subsections. Formula (5) indicates that the completion time of each block must be less than the total completion time of all blocks. Where S_{jf} is the start processing time of the fth process of the jth block, P_{jif} is the time when the fth operation of the jth block was constructed by the ith working team.

$$S_{jf} + X_{ijf} \times P_{jif} \le C_{jf} \tag{3}$$

$$C_{jf} \le S_{j(f+1)} \tag{4}$$

$$C_j \le \max\left(C_j\right) \tag{5}$$

(4) Working team constraints

Formulas (6) and (7) indicate that a working team is responsible for constructing only one block at a time. Formula (8) indicates that each process can only be constructed by one working team. Among them, P_{jif} represents the time when the fth operation of the jth block is processed by the ith working term.

$$S_{jf} + P_{jif} \le S_{kf} + Q\left(1 - Y_{ijfk}\right) \tag{6}$$

$$C_{jf} \le S_{j(f+1)} + Q\left(1 - Y_{ijk(f+1)}\right) \tag{7}$$

$$\sum_{i=1}^{m_{jf}} X_{ijf} = 1 \tag{8}$$

(5) Spatial constraints

Formulas (9) indicates that the length and width of all blocks must be smaller than the length and width of the workshop. Formulas (10) indicates that there is no interference between all blocks and the workshop. Formulas (11) and (12) respectively indicate that when any two blocks have the same x and y values, there is no overlap in other directions. Where (l_j, w_j, x_j, y_j) respectively represent the length, width, and reference point indicators of the blocks, (L_k, W_k) is expressed as the length and width of the workshop.

$$\max\left(l_j\right) \le L_k \ \ and \ \ \max\left(w_j\right) \le W_k \tag{9}$$

$$y_j + w_j \le W_k \ \ and \ \ x_j + l_j \le L_k \tag{10}$$

$$x_j + l_j \le x_k \ \ when \ y_i = y_k \tag{11}$$

$$y_j + w_j \le y_k \ \ when \ x_i = x_k \tag{12}$$

Algorithm for the spatial scheduling-workforce assignment problem

This paper proposes a dynamic spatial scheduling-workforce assignment algorithm based on a two-stage mixed scheduling algorithm. This algorithm firstly uses a multi-layer coding genetic algorithm to obtain the optimal block scheduling sequence and working team arrangement and then uses the average maximal free rectangle space strategy to determine the spatial position of each block.

Identification of block Scheduling sequence and working team arrangement.

This paper uses a multi-layer coding genetic algorithm to determine the optimal block scheduling sequence and working team arrangement. The algorithm includes coding and decoding program, fitness function design, selection, crossover and mutation operation. Table 1 is the specific setting of the multi-layer coding genetic algorithm.

(1) Coding program. This paper adopts the method of multi-layer coding, the meaning of the first layer coding of the chromosome is the processing order of blocked process, and the meaning of the second layer coding is the working team responsible for each process.

(2) Decoding program. Through the decoding process, according to the gene sequence selected by the working team, this paper obtains the processes for which each processing team is responsible; Blocks for each working team; Start time and completion time for each process; Free time of each working team.

(3) Fitness function. For the optimization problem of workshop scheduling in this paper, the fitness function value of chromosomes can be set as the completion time of all blocks, and the formula of fitness value is as follows:

$$fitness(i) = 1/c + m \tag{13}$$

Among them c refers to the processing completion time of all blocks.

(4) Selection, crossover and mutation operation. In this paper, the roulette method is used to design the probability of chromosome selection, integer crossover method is used to crossover operation, and the random mutation method is used to carry out mutation operation.

Table 1. Setting of Algorithm Parameters

Parameter	Setup
Number of individuals	40
Maximum genetic algebra	100
Generation gap	0.9
Crossover rate	0.56～0.80
Mutation rate	0.33～0.60
Genetic operators	Roulette
Generation counter	0
Number of processes	6
Number of blocks	10
Number of working teams selected for each process	332322

The average maximal free rectangle space method.

In this paper, the average maximal free rectangle space strategy is used for spatial positioning. In different positions occupied by the same block, the different average maximal free rectangle space is obtained. After comparison, the location point with the largest area is selected to determine the position of the block.

Step 1: Arrange all the blocks in the processing order, and the blocks perform a cornering action in the field horizontally. If it fails, the block is rotated by 90 ° for the cornering action; otherwise go to step 5.

Step 2: Calculate the average maximal free rectangle space area for all effective angular action positions.

Step 3: Select the position with the average maximal free rectangle space area as the spatial positioning position for the unscheduled blocks.

Step 4: When unscheduled blocks cannot be placed on the workshop, the workshop is adjusted using a fixed backtracking strategy. If the venue has available space, place the blocks; if still cannot place the block, return to step 1 to sort.

Case study

To verify the feasibility of the model and algorithm, this article chooses a section of the ZJ shipyard as a typical example of a total of 30 sections of 3 ships between March and October 2019. The workshop is 88 meters in length and 36 meters in width. Each block needs to go through 6 procedures. Table 2 shows the temporal and spatial attributes of all blocks.

Table 2. Temporal and spatial attributes of blocks

Block ID	Tyre frame	Board	Mark off	Structure welding	Cover plate	Welding	L/m	W/m
1	[3,2,2]	[1,2,3]	[2,2]	[23,27,24]	[3,5]	[2,3]	21	9
2	[3,2,3]	[3,2,3]	[1,2]	[25,28,21]	[2,4]	[2,4]	11	5
3	[1,2,3]	[4,3,2]	[2,1]	[29,25,22]	[5,4]	[3,4]	11	5
…	…	…	…	…	…	…	…	…
30	[3,2,4]	[2,1,3]	[2,3]	[36,34,33]	[3,2]	[4,3]	13	10

Result

Among the spatial scheduling-workforce assignment problem, time will affect the release of space resources, and the size of space resources will also affect time. Based on the multi-layer coding genetic algorithm to obtain the optimal scheduling sequence of blocks, considering the size of the workshop area and blocks, the optimal spatial scheduling-workforce assignment scheme is obtained based on the average maximum residual space strategy. The results are shown in Table 3.

Table 3. spatial scheduling-workforce assignment plan

Number	Block ID	Envelope angle	Coordinates of reference points	start time
1	6	0	(0,0)	2018/3/1
2	25	0	(21,0)	2018/3/1
3	7	0	(0,9)	2018/3/1
...	...	...	...	...
30	4	0	(73,0)	2018/4/24

By comparison with the original scheme, the spatial scheduling-workforce assignment scheme based on multi-layer coding genetic algorithm and average maximum residual space strategy reduces the completion time by 7.22%, the average spatial utilization ratio and the maximum space utilization ratio increased by 20.46% and 10.78%, respectively.

Table 4. Comparison of scheduling schemes

Index	Original scheme	Existing scheme	relative change
Average spatial utilization ratio	43.35%	52.22%	20.46%
Maximum spatial utilization ratio	76.54%	84.79%	10.78%
Completion Time (day)	180	167	-7.22%

Acknowledgements

This study was supported by the Philosophy and Social Science Research Project of Jiangsu Provincial Department of Education [2018SJA1089].

Reference

[1] Z. Zhang, and J. Chen: International journal of production research, Vol 50 (2012) No.10, p.2732.

[2] Y. Ge, A. Wang, and J. Cheng: (2016) International Forum on Management, Education and Information Technology Application(Guangzhou, China, January 30-31, 2016). Vol. 47. p.658.

[3] Z. Zhang, Y. Zen, and J. Chen: Industrial Engineering Journal, Vol 14 (2011) No. 3, p.96.

[4] J. Wang, J. Du, X. Fan and Q. He: Computer Integrated Manufacturing Systems, Vol 21 (2015) No.11, p.2945.

[5] L. Zhuo, D. C. K. Huat and K. H. Wee: International Journal of Production Research, Vol 50 (2012) No.20, p.5986.

[6] S. Hu, T. Liu, S. Wang, Y. Kao and X. Sun: Discrete Dynamics in Nature and Society, Vol 2015, p.841637.

[7] J. Zheng, Z. Jiang, Q. Chen, and Q Liu: International Journal of Production Research, Vol. 49 (2011) No.8, p.2351.

[8] J. Zheng, Z. Jiang,and Q. Chen: International journal of production research, Vol. 50 (2012) No.10, p.2744.

[9] N. Tao, Z. Jiang, and L. Zhen: Asia-Pacific Journal of Operational Research, Vol 31 (2014) No. 01, p.1450006-1.

[10] S. Hu, S. Wang, Y. Kao, T. Ito and X. Sun: Mathematical Problems in Engineering, Vol 2015, p.628259

[11] L Dai, H Hu, F Chen: Ships and Offshore Structures, Vol 10 (2015) No.6, p.660.

[12] H. Liu, X. Yu: Computer Engineering and Applications, Vol 52 (2016) No.22, p.226.

[13] C. Lu, S. Ma: Computer Engineering and Applications, Vol 33 (2013) No.2, p.333.