Research on Construction and Scheduling of Seru Considering Worker Flexibility

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Abstract. Seru have gradually become the production method to cope with multi-variety and small-lot demands due to their high productivity and flexibility, and the allocation of tasks, equipment and workers are the key decisions in the construction and scheduling of Seru. In this paper, an optimization model with the objectives of minimizing the maximum completion time and workload balance among workers is established and solved by the improved NSGA-II algorithm, and finally the effectiveness of the model and algorithm is verified by numerical examples.

Keywords: Seru construction and scheduling · Worker flexibility · Workload balance · NSGA-II

1 Introduction

In recent years, with the continuous development of information technology and automation technology, product life cycle is getting shorter and customer demand is diversified, enterprises need to shorten production cycle and increase effective output. In this case, mass production and other traditional production methods can no longer meet the market demand. Besides, the traditional assembly line line is not economical enough due to high labor cost, therefore, enterprises should seek new production methods.

Seru is the Japanese pronunciation of "Cell", which stands for a production cell, an assembly cell consisting of a light machine with a wheeled table, a hand-held tool, an all-rounder or several multi-taskers. It is mainly studied by equipment or workers to determine the grouping of equipment and workers and their working methods to improve the productivity of the workshop. In this paper, with the objective of minimizing the maximum completion time and workload balance among workers, we conduct a study on the construction and scheduling of Seru production cell considering the flexibility of workers.

2 Literature Review

Sun [1] proposed a co-evolutionary algorithm with the objective of minimizing the maximum completion time, which combines genetic algorithm and ant colony algorithm, where genetic algorithm is used to solve the construction problem of Sai Roo

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and ant colony algorithm is used to find the optimal order scheduling problem, and the two evolutionary algorithms collaborate with each other to find the optimal solution of the problem. Zhang [2] studied the scheduling problem of the Sailu production system with the objective of minimizing the maximum completion time and developed a particle swarm algorithm based approach to solve the problem. Wang [3] set up a multi-objective model to minimize the total variable cost and minimize the total idle time, and studied the order scheduling problem in Seru production system considering the distribution of workers, and used the K-means clustering algorithm to solve the distribution of workers, and used the artificial colony algorithm to solve the order scheduling problem. Luo [4] constructed the Seru scheduling problem considering worker allocation into a two-layer programming model. The upper worker allocation problem aims to minimize the total idle time and the lower worker allocation problem minimizes the maximum completion time by finding the optimal order allocation. An optimization algorithm combining simulated annealing and genetic algorithm is proposed to solve the problem. Ying [5] studied the problem of training and allocation of multi-skilled workers in Seru systems, and designed a two-stage heuristic algorithm to solve the problem effectively and efficiently, taking the balancing cost of worker training cost and processing time as the optimization objective. Yu [6] He considered to convert the production line into a pure Seru production system, and analyzed the mathematical characteristics such as solution space, complexity and non-convexity of the conversion problem, and used NSGA-II to solve the problem. Ömer Faruk Yılmaz [7] studied and discussed the labor scheduling problem in Seru production environment, developed several algorithms with two different initial population generation processes for large problems, and studied in detail the impact of the realization of underhumanization and the heterogeneity of workers. Seru construction and scheduling model considering worker flexibility.

3 Seru Construction and Scheduling Model Considering Worker Flexibility

3.1 Problem Description

The problem is described as follows: There are p types of products, m sets of equipment, w workers with different skill levels, and b batches to be produced in the workshop. Each product contains S processes, the process set of each product is y, and the standard working time of different equipment to complete the process is Op. There is a corresponding relationship between workers with different skill levels and equipment types. The skill level of each worker is different. The set of working time coefficients of workers is tpsm, which determines the actual working time of workers operating a piece of equipment to complete a job.

The problems studied in this paper mainly include the following assumptions:

(1) Product type and batch size are known, and batch segmentation is not considered;
(2) A batch can only be assigned to one Seru;
(3) The working time of each process of the product is known;
(4) The skill level of workers is fixed;
(5) All equipment and workers need to be divided into a certain unit;

(6) The movement time and distance of workers are not considered;
(7) Do not consider the workers operating different equipment switching time;

3.2 Symbol Definition

In this paper, the size of batch b is expressed as V_b; the assembly time of process s of product type p on equipment m is represented by t_{psm}; f_{mps} denotes the operating capacity coefficient of equipment m; C_b represents the assembly completion time of batch b. In addition, the model in this paper also contains some 0–1 variables, and set

$$L_{bp} = \begin{cases} 1, & \text{If batch } b \text{ contains product type } p \\ 0, & \text{otherwise} \end{cases};$$

$$y_{ps} = \begin{cases} 1, & \text{If the production process of product } p \text{ includes process } s \\ 0, & \text{otherwise} \end{cases};$$

$$U_{ms} = \begin{cases} 1, & \text{If equipment } m \text{ can assemble process } s \\ 0, & \text{otherwise} \end{cases};$$

$$Z_{wm} = \begin{cases} 1, & \text{If worker } w \text{ can operate equipment } m \\ 0, & \text{otherwise} \end{cases}.$$

$$O_{bc} = \begin{cases} 1, & \text{If batch } b \text{ is assigned to Seru } c \\ 0, & \text{otherwise} \end{cases};$$

$$X_{wc} = \begin{cases} 1, & \text{If worker } w \text{ is assigned to Seru } c \\ 0, & \text{otherwise} \end{cases};$$

$$Y_{mc} = \begin{cases} 1, & \text{If equipment } m \text{ is assigned to Seru } c \\ 0, & \text{otherwise} \end{cases};$$

$$A_{psm} = \begin{cases} 1, & \text{If process } s \text{ of product } p \text{ is allocated to equipment } m \\ 0, & \text{otherwise} \end{cases};$$

$$Q_{mw} = \begin{cases} 1, & \text{If equipment } m \text{ is assigned to worker } w \\ 0, & \text{otherwise} \end{cases}.$$

3.3 Mathematical Model

Objective functions

$$\min\{\max C_b\} \tag{1}$$

$$\min WB = \frac{1}{C}\sum_{c=1}^{C}\left[\sum_{b=1}^{B}\sum_{p=1}^{P} O_{bc}L_{bp}V_{bp}\sum_{s=1}^{S} y_{ps}A_{psm}t_{psm}\sum_{w=1}^{W}\sum_{m=1}^{M} X_{wc}Y_{mc}Z_{wm}U_{ms}f_{mps} - \overline{C}\right]^2 \tag{2}$$

among $C_b = \sum_{b=1}^{B} \sum_{p=1}^{P} \sum_{s=1}^{S} L_{bp} y_{ps} A_{psm} U_{ms} X_{wc} Z_{wm} t_{psm} V_b$;

$$\overline{C} = \frac{1}{C} \sum_{c=1}^{C} \sum_{b=1}^{B} \sum_{p=1}^{P} O_{bc} L_{bp} V_{bp} \sum_{s=1}^{S} y_{ps} A_{psm} t_{psm} \sum_{w=1}^{W} \sum_{m=1}^{M} X_{wc} Y_{mc} Z_{wm} U_{ms} f_{mps}$$

subject to

$$\sum_{c=1}^{C} O_{bc} = 1 \tag{3}$$

$$\sum_{c=1}^{C} X_{wc} = 1 \tag{4}$$

$$\sum_{c=1}^{C} Y_{mc} = 1 \tag{5}$$

$$1 \le \sum_{w=1}^{W} X_{wc} < W \tag{6}$$

$$1 \le \sum_{m=1}^{M} Y_{mc} < M \tag{7}$$

$$1 < C \le B \tag{8}$$

$$A_{psm} \le U_{ms} \tag{9}$$

$$Q_{mw} \le Z_{wm} \tag{10}$$

$$\sum_{m=1}^{M} Y_{mc} = \sum_{w=1}^{W} X_{wc} \tag{11}$$

Equations (1) and (2) are objective functions, which respectively represent minimizing the maximum makespan and minimizing the workload variance among workers. Equation (3) ensures that each batch is allocated to only one Seru. Equations (4) and (5) ensure that each worker and each piece of equipment is assigned to only one Seru. Equations (6) and (7) respectively limit the number of workers and equipment that a Seru can accommodate. Equation (8) indicates that the number of constructed Seru is at least 1, but not more than the batch number B. Equations (9) and (10) ensure that the processes assigned to the equipment are those in which the equipment can be assembled and the equipment assigned to the worker in Seru is the equipment that the worker can operate. Equation (11) ensures that one worker can only operate one device in the Seru.

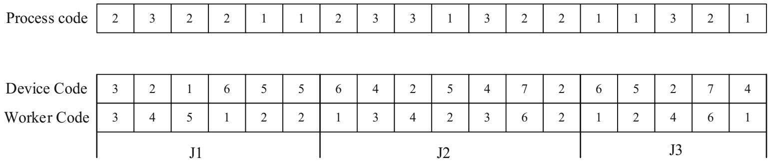

Fig. 1. Three-dimensional chromosome coding

4 Algorithm Design

4.1 Encoding and Decoding

Three-dimensional chromosome coding is adopted in this paper, as shown in Fig. 1.

In this paper, the chromosome is decoded according to the information of available workers and available processing equipment, and specific equipment and workers are selected for each processing process.

4.2 Selection, Crossover and Variation

(I) Select operation

In this paper, chromosomes are divided into two sets, corresponding to high-quality solutions and non-high-quality solutions respectively, and non-dominant sequencing is performed. In the selection process, high-quality solutions are selected first, and if the number of high-quality solutions is less than the set number of chromosomes, then non-high-quality solutions are selected.

(II) Cross operation

This paper uses IPOX cross operation based on process coding. as shown in Fig. 2.

Devices are crossed randomly as shown in Fig. 3.

The worker chromosomes crossover is similar to the equipment chromosomes.

(III) Mutation

Process variation adopts random insertion variation, as shown in Fig. 4.

Device variation randomly selects a gene on the device chromosome and randomly selects a replacement gene from the processable set, as shown in Fig. 5.

Worker chromosome variation is similar to equipment chromosome variation.

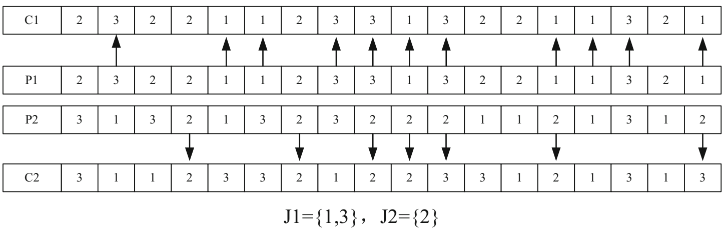

Fig. 2. Step crossing operation

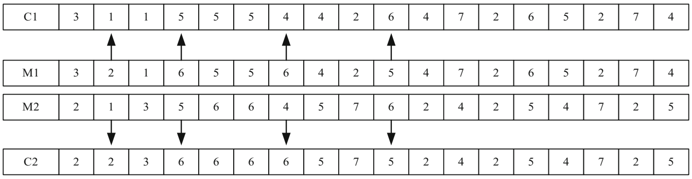

Fig. 3. Equipment crossing operation

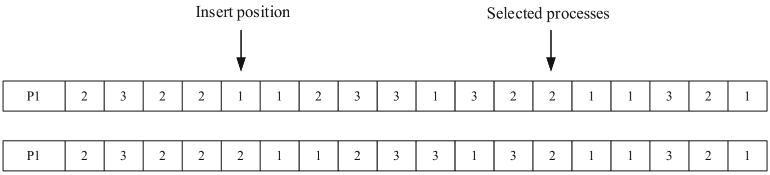

Fig. 4. Process variation

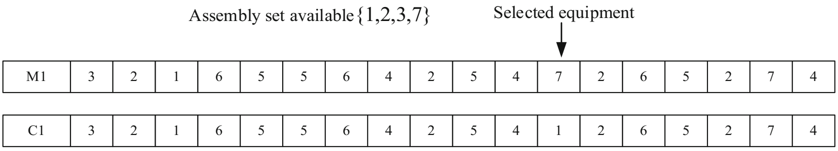

Fig. 5. Equipment mutation

Table 1. Product Batch Information

Batch	B_1	B_2	B_3	B_4	B_5	B_6
Product type	1	2	3	4	5	6
Number of batch	6	4	6	7	5	7

5 Example Analysis

5.1 Example Basic Data

Table 1 shows product batch information, mainly including product type and batch size. Table 2 shows the information related to product production, including product type, product process and processing time. Table 3 shows the coefficient of skill level of workers in operating equipment.

5.2 Analysis of Numerical Results

In this paper, the algorithm parameters of NSGA-II were set as follows: the population size was 200, the crossover probability was 0.8, the mutation probability was 0.2, the upper limit of algorithm iteration was 100, and the termination condition was to reach the

Table 2. Product production information

Product type	Work sequence	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8
P1	1-1	5	—	—	—	6	—	6	—
	1-2	—	—	5	—	7	—	—	8
	1-3	4	—	—	5	—	6	—	—
	1-4	—	—	5	—	6	4	—	—
P2	2-1	5	4	—	6	—	—	—	—
	2-2	—	—	—	—	5	—	7	—
	2-3	—	—	7	—	6	—	—	9
	2-4	—	8	—	9	—	—	9	—
P3	3-1	—	—	6	—	5	—	7	—
	3-2	—	7	8	—	—	—	—	8
	3-3	—	5	—	—	7	—	7	—
P4	4-1	—	—	—	7	9	—	8	—
	4-2	9	—	—	—	9	—	—	7
	4-3	—	—	—	8	—	7	6	—
P5	5-1	—	8	—	6	—	—	—	9
	5-2	8	—	—	—	9	—	7	—
	5-3	—	—	6	—	—	—	8	5
	5-4	10	—	—	7	9	—	—	—
P6	6-1	7	—	—	—	—	6	8	—
	6-2	—	—	8	9	—	10	—	—
	6-3	8	—	6	—	7	—	—	—

Table 3. Worker skill proficiency level coefficient

Workers	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8
w1	0. 9	0. 9	—	—	0. 8	—	—	1. 0
w2	0. 8	—	1. 0	—	—	0. 9	—	—
w3	—	1. 0	0. 9	0. 8	—	—	—	0. 8
w4	—	—	—	1. 0	0. 9	—	0. 9	—
w5	0. 8	—	—	—	—	1. 0	—	—
w6	—	—	0. 9	—	1. 0	1. 0	0. 9	—
w7	—	0. 8	—	0. 9	—	—	1. 0	0. 8
w8	1. 0	—	0. 8	—	0. 9	—	—	0. 9

Table 4. Numerical arithmetic non-dominated set

Non-dominated solutions	1	2	3	4	5	6
f_1	140	153	158	162	174	186
f_2	1028. 6	986. 7	936. 3	756. 9	681. 5	675. 6

predetermined number of iterations. Table 4 shows the non-dominated set of numerical examples when three Serus are constructed.

Through the non-dominated solution set of the numerical example, it can be seen that the minimum completion time is 140 h, and the variance of workers' workload is 1028. 6, and the workload among workers is relatively unbalanced. The maximum completion time is 186 h. At this time, the variance of workers' workload is 675. 6, and the workload among workers is in a relatively balanced state.

6 Conclusion

In this paper, we study the Seru production cell construction and scheduling problem in the case that there are differences in the skill proficiency levels of workers operating the equipment in the equipment-based Seru production cells. In this paper, the maximum completion time and worker workload balance indexes are considered in the Seru production cell construction and scheduling model, and the model is solved by the improved NSGA-II algorithm. The rationality of the Seru construction and scheduling model constructed in this chapter and the effectiveness of the algorithm are verified by combining with arithmetic examples, which effectively guarantee the fairness among workers and the stability, continuity and efficiency of the production system.

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