Line Operation Planning in a Multi-Product Sewing Shop

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Abstract

In the fashion industry, there are a large number of products because of the various and seasonal designs. In addition, due to workers' different work experiences, the processing time of an operation differs largely among workers. Moreover, as the products are produced in small lot sizes, product switches happen frequently so that the changeover time of a sewing line is long.

Therefore, the line operation planning in such lines is not only a single line balancing problem but a complex and large scale problem of decision making. It has to determine not only each product's operations & workers assignment to workstations but also the products' execution sequencing in a line. Currently, a key problem is that the productivity of such lines is very low.

In this paper, the previous planning system is proved not suitable for the operation planning in the kind of line whose decision sequence is to first assign each product's operations to workstations and then assign workers to the workstations, and in which the changeover time is not considered.

In order to solve this problem, a planning system that can make these two decisions simultaneously is proposed, and its effect on shortening the makespan is confirmed.

Keywords:

Sewing line, Line balancing, Operation planning

1. Introduction

Nowadays, the employment affairs at companies have changed. In order to decrease production costs, the number of regular employees is decreased; in their place, Hisashi Onari Dept. of Industrial and Management Systems Engineering, Waseda University onari@waseda.jp

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more temporary employees are hired, who will work under a short-term (i.e., 2-3 years) contract or only work part-time. Therefore, in a manual assembly factory, especially one in which high operation skills are required, it is rare that all workers are trained in multiple skills because it requires a long training and practice period. New workers are assigned to a assembly line after a short-term off-line training period. Though they can execute various operations, their skill levels are still low and need to be improved during on-the-job training. It is no exaggeration to say that it may take a couple of decades to be a perfect multi-skilled worker.

In the fashion industry, because of the design variety and the seasonality, there are various production types in a sewing line, and the production mix may change greatly every month. Especially in the undergarment industry, various designs and fabrics for undergarments have been developed to make women feel more comfortable and beautiful during recent decades. However, because of the difficult product structure and the features of its materials (e.g., elasticity, softness, etc.), a relatively long learning period is required for workers to master a sewing operation. Therefore, due to the different work experience of each kind of worker, skill-level gaps exist, which means the processing time of an operation differs largely among workers.

In this production environment, line operation planning is a large scale and complex issue, which determines both product execution sequence and operations & workers assignments to workstations. And its result impacts the productivity of a sewing line largely. Through some investigation in a well-known global undergarment-sewing firm, it has become clear that one of the most important issues is improving worker productivity. In order to solve this problem, methods should be developed for training workers to become multi-skilled ones in a short period, correctly evaluating worker skill level, and assigning sewing operations to the suitable worker. In this paper, the later topic is focused on, a method of operation planning in a multiple-product sewing line is proposed and tested, and also a typical traditional line operation planning system is discussed.

2. Definition of Operation Planning in a Multiple-Product Sewing Line

A sewing work is defined as the set of sewing operations needed to complete an entire product; for example, to produce a brassiere is a sewing work. And here, a sewing operation is defined as the smallest indivisible work element such as any act of joining two or more parts of a fabric with a sewing machine. Among sewing operations, processing technological precedence relationships exist.

A sewing line produces a set of products, and it consists of a set of workstations. A workstation is a location along the flow line where one or more operations of a product are processed, and it consists of a set of sewing equipment that can deal with multiple sewing operation types. However, in each workstation only one worker is allocated. Operations of different products cannot be processed alternately. And a worker can only process the operations assigned to one workstation.

In this paper, operation planning of a multiple product line involves the following 3 decisions.

- D-1: Operations of each product that will be processed at each workstation
- D-2: Worker allocation to workstations of each product
- D-3: Product execution sequence

And the problem is done under the following assumptions.

- A-1:An operation cannot be split amongst two or more workstations.
- A-2:Technological precedence sequence requirements must be satisfied.
- A-3:All operations on products must be processed.

A-4:All workstations are equipped to process any of the

operations.

A-5:Worker processing time of an operation is not equal; it depends on a worker's skill at a particular operation.

[Evaluation parameters of line operation planning]

The purpose of operation planning in a multi-product line is to minimize total time required for completing all the products (makespan, hereafter).

And, Equation (1) is used to evaluate the line balancing result of each product, where WL_{im} is the workload of product *i* in workstation m (m=1,2,...K).

$$LB_{i} = \frac{\sum_{m=1}^{K} WL_{im}}{Max(WL_{im}) \times K} \times 100 \qquad (\%) \qquad (1)$$

3. Analysis of Current Line Operation Planning System

The first decision (D-1) problem mentioned in the last section is also called the line balancing problem (LB problem, hereafter), whose purpose is to minimize the cycle time of a line. It has been studied widely for the past several decades, and a large number of optimal and heuristic solution procedures have been developed and reported. For instance, a survey of exact algorithms for the simple (one product) assembly line balancing problem was done by Baybars in 1986. After that still more algorithms were developed. In those studies, the processing time of an operation is given and fixed (which means it does not depend on workers). However, in a line where skill level gaps among workers exist, the processing time of an operation largely depends on the allocated worker's skill level. Accordingly, the current determination procedure of line operation planning is limited, which is to first assign operations to workstations, and then to assign workers to the workstations. Because at the first step, before worker assignment, the actual processing time of an operation is not known, only average or standard time can be used in the calculation of balancing each workstation's workload. Though a good solution can be worked out in this step, however, after the worker assignment problem is solved out, the line balance loss will exactly increase.

On the other hand, as operations & workers assignment to workstations of each product is determined

separately, workers may have to move to their assigned locations when a product switches. Therefore, line changeover time includes not only the time loss due to different cycle time between adjacent products, but also the mentioned transportation time.

In order to verify whether these phenomena exist or not, the following numerical simulation is done. Figures 1 and 2 show the results.

[Simulation conditions]

- Operations involved in the product: 15-30
- Number of product types: 6-20
- Number of workstations: 5-10
- Difference in worker skill level in an operation:
 0.5-5 (Standard skill level coefficient is defined as 1)

[Decision procedure]

D-1: The famous algorithm of Helgson & Birnie is used. The positional weight of an operation is defined to be the sum of the processing time of that operation and that of the following operations. Operations are ranked in descending order of these weights, and then assigned to the workstations in that order while not violating the precedence constrains. The function is to minimize cycle time.

D-2: In this step, the worker who can execute the target operation in the shortest processing time is selected. At the same time, the workload of each worker is also considered.

[Results]

Figure 1 shows the line-balancing results. It is obvious that the line balance rate decreased largely after workers are assigned to workstations (WSs). Therefore, when workers' processing time of an operation are largely different, the current line operation planning method is not suitable, which determines operation of products assignment and workers assignment separately.

On the other hand, from Figure 2, it is clear that 1/3 of the line loss time is changeover time due to product switch. Therefore, it is also necessary to develop line operation planning methods to decrease such time loss.



Figure 1. Line balance result



Figure 2. Details of line operating state

4. Proposal of Operation Planning in a Multi-Product Sewing Line

In this section, a line operation planning method is proposed for a multi-product sewing line, which is based on the following two key ideas:

- Assigning operations of a product directly to workers
- Assigning operations of each product with consideration of workers' locations of each product

Because the line operation planning problem includes several decision-making problems, as we mentioned above, it is a large-scale and complex problem and difficult to solve. In order to obtain a good solution, the concept of genetic algorithm is adopted. The initial solutions and improvement processes are proposed as follows, both of them involve the afore mentioned basic ideas. Before the detailed description, the basic concept of the genetic algorithm (GA, hereafter) is shown. [Introduction of GA]

Genetic algorithms are inspired by Darwin's theory of evolution. The algorithm is started with a set of solutions (represented by chromosomes) called population. Solutions from one population are taken and used to form a new population. This is motivated by a hope that the new population will be better than the old one. Solutions which are selected to form new solutions (offspring) are selected according to their fitness - the more suitable they are the more chances they have to reproduce. This is repeated until some condition (for example, the number of populations or the improvement of the best solution) is satisfied.

The basic steps can be described as follows:

- Step 1: Generate initial population of a set of chromosomes (initial solutions).
- Step 2: Evaluate the fitness f(x) of each chromosome x in the population.
- Step 3: Create a new population by repeating the following steps until the new population is complete.
 - Select two parent chromosomes from a population according to their fitness (selection).
 - Cross over the parents to form a new offspring (crossover).
 - Mutate new offspring at each locus (position in chromosome) with a mutation probability (mutation).
 - Place new offspring in a new population (accepting).
- Step 4: Repeat step 2 and step 3 until the end condition is satisfied, and return the best solution in the current population.

Line operation plan of product 1

[Initial solutions creation]

The initial solutions are created by the following procedures.

- Step 1: Calculate worker average processing time of each operation involved in each product, and then calculate the average workload of a worker in each product as a reference value (cycle time).
- Step 2: If it is the first time to select a product, select it randomly. Otherwise, select the product to be the next target of assignment, which has more similar operations to the previous assigned one. (If the operation combinations are similar, it can be considered that the worker may have a high possibility of being assigned similar operations and their location may not need to change when the product switches.)
- Step 3: Randomly select a worker and assign the operations to him/her considering the workload and operation processing precedence limitations.
- Step 4: Repeat 3 until all the operations are assigned to workers and all workers are assigned operations. If there remain operations which are not assigned, then increase one unit of the referenced cycle time, and reassign all the operations with procedure 3. If all operations are assigned, but there exist workers who have no assigned operations, then decrease one unit of the referenced cycle time, and reassign all the operations again with procedure 3.
- Step 5: Repeat steps 2-4 until all the products are assigned.

[Chromosomes descriptions]

All the initial solutions are represented as chromosomes as follows.

Line operation plan of product *i*



Figure 3. Representation of a chromosome

In order to decrease makespan, the following parameters should be shortened: processing time, line time losses due to both unbalanced workload of workers and product switch. Therefore, each solution is represented as a chromosome, as in Figure 3. The processing time of an operation can be considered to be shortened if its execution worker is changed. And line loss time can be decreased by changing workers' operations or the product execution sequence. Therefore, all the changeable parameters are described as a gene.

[Crossover and mutation]

A pair of solutions (parent chromosomes) are chosen for crossover, whose evaluation values (fitness) are high (makespan is short). Crossover selects genes from parent chromosomes and creates a new offspring. In this study, the parent chromosome with the shortest makespan is chosen, and its bad genes are selected to be rewritten with those of the other parent chromosome. The following 3 methods are proposed for crossover point (bad genes) selection.

- Worker operation sequence of the product which has the longest total processing time
- Operation assignment to each worker of the product with the largest line balance loss
- Product execution sequence

Mutation takes place after crossover, a product is selected randomly and the set of its genes are exchanged with a randomly selected parent chromosome.

Population size is set in advance, which means how many chromosomes are in a population (in one generation). So all the created new offspring are evaluated, and only the chromosomes with the good evaluation values remain in the new generation.

The number of continuous generations without improvement is also set in advance, and the algorithm ends when the number is exceeded.

5. Effect of Proposed Line Operation Planning System on Shortening the Makespan

The proposal is evaluated by comparing it with the method of enumeration, which is to list up all the solution candidates to find the best solution. Table 1 shows a sample result of the comparison. It is a result examined with a small-scale problem, where there are

only 3 products and 3 workers, the number of operations involved in each product is 7, and lot size of a product is 50-150. Difference in worker skill level of an operation type is about 0.5-5.

Table 1. Proposal evaluation result

Solving method	Makespan (sec.)	Number of searched solutions
Enumeration method	18880	25200
Proposal	19784	182 (27 generations)

Table 1 shows that there is only about 5% difference in makespan between the two methods. Moreover, it is obvious that the proposal needs fewer search times, which means it requires less time to obtain a good solution. This is important because in a real line, the problem scale is always large and needs more time in solving the line operation planning problem.

Also, the proposal is evaluated by the simulation shown below. It is compared with the traditional method which is to first assign operations to workstations and then to assign workers to workstations. A sample result is shown in Table 2.

[Simulation conditions] Product types: 10-20 Operations involves in each product: 10-20 Lot size of a product: 50-150 Difference in worker skill level of an operation type: 0.5-5

Table 2.Comparison of proposal and the traditional method

Solving method	Makespan (sec.)	(Changeover time/makespan) × 100 (%)
Proposal	56765	1.7
Traditional method	59357	7.3

From Table 2, it is clear that the makespan of the proposal is short when compared with that of the traditional method. It is not only the result that line time loss due to product switch is decreased, but also the result that a good line balancing is achieved by assigning operation directly to workers.

6. Conclusion

In this study, it is pointed out that in a manual line (such as a sewing line) where new employees appear frequently, worker skill level in an operation differs largely. Therefore, the traditional line operation planning method occur time losses due to both unbalanced workloads and product switch, which determine the operation & worker assignment problems and product execution sequence problem separately.

In order to improve the performance of a line, an integrated method based on the genetic algorithm is proposed, and its effect on shortening the makespan is confirmed.

However, more analyses and examinations should be done to clarify the essential qualities of multi-product line operation planning procedure.

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