A Study on Line Operation Planning for Sewing Works

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ABSTRACT
This paper focuses on multi-product sewing shops, in which there are various products and the operations combination for completing each product differs largely among products, and in which skill levels differ largely among workers. As basic research, this paper discusses one sub-problem of multi-product line operation planning: the single-product line operation planning problem, which includes not only the operation assignment problem but also the worker allocation problem for a product.

Firstly, from a survey of the literature and investigation of real sewing shops, we clarify that there are two typical line operation planning methods. Both of them determine the above two problems separately, and the difference between them is the solving procedure: one method first assigns operations and then allocates workers to the workstations of the line (Method A), while the other takes the opposite procedure (Method B). Secondly, we carry out numerical experiments and clarify that Method A will cause large line balance loss when the varieties of operation and worker ability are large. Thirdly, in order to implement Method B under the new production environment, algorithms for worker allocation are proposed and discussed. The effects of Method B on decreasing line balance loss and cycle time are confirmed. We also point out that Method B can still be improved. In order to obtain a good operation plan for such lines, methods which can solve these two problems together should be developed, instead of solving them separately.

Key words: Sewing Work, Operation Assignment, Worker Allocation, Line Balancing

1. INTRODUCTION
In the fashion industry, due to design variety and product seasonality, there are various products in a sewing shop and the product mix changes greatly every month. In this paper, we will focus on undergarment sewing shops. As the undergarment is required to directly and comfortably fit the body, various undergarment designs and fabrics have been developed in the last several decades. However, according to a garment's structure and material features (e.g., elasticity, softness, etc.), the operations of undergarment production are relatively difficult. A key problem is that the productivity of undergarment sewing shops is low.

In this chapter, the characteristics of an underwear sewing shop and its production method will be discussed.

Sewing an undergarment requires a set of operations consisting of several operation types. Moreover, the operations combination differs greatly among products. Most of the operations are sewing operations, which are processed by workers with sewing machines. As undergarment sewing operations are relatively difficult, it takes a long learning period for a worker to master an operation.

Workers in a sewing shop are composed of regular members and contract-based employees, so that replacement of workers occurs once or twice a year. The fresh workers are assigned to workstations after basic training, such as how to operate sewing machines or how to perform basic sewing operations. After that, they have to improve their operation skill level during on-the-job training. Therefore, according to different work experiences, the skill level in a given operation differs greatly among workers [1][2][3][4][5]. Nowadays in a sewing shop, there are only a few skilled workers who can deal with all kinds of operations on a high skill level.

Therefore, in our focused sewing shops, for each worker there always exist operations that he/she has not mastered. Under this production environment, the line production system should be adopted, where products are produced in lot units. Because operations of a product are divided among workers and an operation assignment can be executed by product (lot) unit, workers may only deal with the operations he/she has mastered.

However, the line production system also has its demerits. One is that product (lot) switch happens frequently; because the lot size of each product is small (from several hundreds to thousands), so that a line has to produce several kinds of products every day [6]. Another demerit is that for each lot it is difficult to optimize a line operation plan which matches workers to operations so that cycle time can
be minimized and workloads among workers can be balanced, because worker skills differ greatly.

As a basic study, this paper will focus on the latter demerit, the line operation planning problem of a product, which includes the following two problems: the operation assignment problem and the worker allocation problem.

In the past several decades various relevant studies have been conducted [7][8][9], especially on the operation assignment problem (which is also called the line balancing problem) When both problems have to be dealt with, it is common to first assign operations and then to allocate workers to workstations (Method A). However, the production environment changes often, so that the common method may not be suitable in the new production environment. In this paper, a typical algorithm of Method A is discussed by changing the production environment. Also, worker allocation algorithms for Method B (which is to first allocate workers to workstations and then to assign operations to the assigned workers) are proposed and compared. The production environment’s changing trends and the details of Method A and Method B will be introduced in Section 2 and Section 4, respectively.

2. MODEL OF THE OPERATION PLANNING PROBLEM

2.1 Preconditions and Notation
Operation planning for a lot (product) determines the following two sub-problems:
1) Operation assignment
2) Worker allocation

The preconditions of the operation planning problem are shown as follows:

1) A sewing line is composed of a set of workstations. The number of workstations is set in advance.
2) Sewing a product consists of a set of operations. Technological precedence requirements exist among operations, an operation cannot be processed until all of its precedent operations are finished.
3) A worker is assigned to one workstation, and will only process the operations which are assigned to that workstation.
4) An operation cannot be split amongst two or more workstations.
5) Worker processing time for each operation is known.
6) Operation processing time differs among workers because of their varying work experience.

(7) A worker can process all the operations, and his/her work experience differs among operations.

Data and Parameters
\[ k \] a set of workstations \( \{1, 2, \ldots, m\} \)
\[ w \] a set of workers \( \{1, 2, \ldots, m\} \)
\[ j \] a set of operations \( \{1, 2, \ldots, n\} \)
\( \{E_j\} \) the set of operation \( j \)'s precedent operations
\( 1 \leq E_j \leq n \) if \( \{E_j\} \neq \emptyset \) or \( \{E_j\} = \emptyset \)
\( T_w \) worker \( w \)'s processing time for operation \( j \)
\( L_k \) workload of workstation \( k \)
\( z \) cycle time

Decision Variables
\( \{O_k\} \) the set of operations that are assigned to workstation \( k \), \( 1 \leq O_k \leq n \)
\( W_k \) the number of the worker that is assigned to workstation \( k \), \( 1 \leq W_k \leq m \)
\[ x_{jk} = \begin{cases} 1 & \text{if operation } j \text{ is assigned to workstation } k \\ 0 & \text{otherwise} \end{cases} \]
\[ \forall j \in \{1, 2, \ldots, n\} \text{ and } \forall k \in \{1, 2, \ldots, m\} \]
\[ y_{wk} = \begin{cases} 1 & \text{if worker } w \text{ is assigned to workstation } k \\ 0 & \text{otherwise} \end{cases} \]
\[ \forall w \in \{1, 2, \ldots, m\} \text{ and } \forall k \in \{1, 2, \ldots, m\} \]

2.2 Evaluations
The objective function of line operation planning is to minimize cycle time (1). Constraint (2) ensures that each operation is assigned to one workstation, and Constraint (3) ensures that each worker is assigned to one workstation.

Minimize \[ z \] \hspace{1cm} (1)
Subject to: \[ \sum_{k=1}^{m} x_{jk} = 1 \forall j \in \{1, 2, \ldots, n\} \] \hspace{1cm} (2)
\[ \sum_{k=1}^{m} y_{wk} = 1 \forall w \in \{1, 2, \ldots, m\} \] \hspace{1cm} (3)

Equation (4) shows cycle time depends on the maximal workload of the workstation. So if the bottleneck workstation is \( x \), then \( L_x \) can be calculated by Equation (5).

\[ z = \text{Max}(L_1, L_2, \ldots, L_m) \] \hspace{1cm} (4)
\[ L_x = \sum T_{wj} \forall j \in \{O_k\} \quad w = W_x \quad (5) \]

In order to minimize cycle time, the workload of each workstation needs to be minimized. Therefore, the objective function can be also represented as Equation (6).

\[ \text{Min} \sum T_{wj} \quad \forall j \in \{O_k\}, w = W_k \quad \forall k \in \{1, 2, ..., m\} \quad (6) \]

At the same time, in order to decrease the workload of the bottleneck workstation, shifting its workload to other workstations is also important. In other words, it is also important to decrease the line balance loss which is evaluated by Equation (7).

\[ \text{LB Loss rate} = \left(1 - \frac{\sum_{k=1}^{m} L_k}{\max(L_k) \times m}\right) \times 100\% \quad (7) \]

2.3 Production Environment Changing Trends

Recently in our target sewing shops, the following 3 production environment change trends can be seen. The influence of these changes on the performance of line operation planning methods will be discussed in Section 4.

(1) The trend in operation unit size

In order to fit the body perfectly, the product structure becomes more complicated. It is difficult to determine an operation unit with the standard unit size, hence, the size of an operation varies, which means processing time of an operation varies largely among operations (Operation variety ①).

(2) The trend in operation difficulty

Because the product structure became more complicated, and because at the same time more elastic new fabrics have been developed to make people feel more comfortable, more difficult operations appear. Therefore, the difference in operation processing time between a new worker and a skilled worker tends to be large. (Operation variety ②).

(3) The trend in worker ability

As the employment situation changes, it becomes more difficult to employ workers who can work for a company long term. Therefore, more temporary employees are hired in sewing shops. Hence, owing to workers' varying work experience, the difference in work skills at a given operation among workers tends to be large (Worker ability variety).

3. SURVEY OF OPERATION PLANNING METHODS

As we have mentioned above, line operation planning for a product (lot) includes two sub-problems: operation assignment and worker allocation to workstations of the line. Therefore, line operation planning has the following two functions: balancing workloads among workstations and minimizing the processing time of each worker.

From a survey of the literature, it is clear that most research deals with only one of the sub-problems. Only a few researchers deal with both sub-problems, and they all solve the problems separately. This means that the operation assignment problem is solved under the condition that there is no difference in processing time among workers, and the standard or average processing time of each operation is used for calculation. In addition, the worker allocation problem is solved under the condition that each workstation's operations are known. We call this solving procedure Method A, which is defined as follows:

Method A:

Firstly assign operations to each workstation of the line, and then allocate workers to the workstations.

The former sub-problem, which is also called the "line balancing problem," equalizes workloads among workstations so that the cycle time of the line can be minimized. This problem has been studied widely for the past several decades, and a large number of optimal and heuristic solutions have been developed and reported. Moreover, there is also a good deal of research on solution comparison for this problem. For instance, Baybars conducted a survey of exact algorithms [10], and Ghosh compared several famous heuristic procedures [11]. After that still more algorithms were developed [12].

The latter sub-problem, that of worker allocation, has also been studied in recent decades [13][14][15]. According to a worker's skill at a given operation, the processing time of each operation differs greatly among workers; therefore, it is important to match workers to the operations so that total processing time can be minimized.

On the other hand, investigation of real undergarment firms and shops has also been conducted. As a result, we find that it is common to allocate workers to the sewing line in the high skill level sequence. The worker with the highest skill level will be allocated to the first workstation of the line, with the aim of decreasing idle time of the downstream workstations. Operation assignments are executed after worker allocation; therefore, instead of using
standard or average processing time, as in Method A, each worker's processing time is used. We call this line operation planning procedure Method B.

Method B:
First allocate workers to each workstation of the line, and then assign operations to the workstations.

In our target sewing lines, operations and worker skill levels at each operation vary largely. Therefore, Method A can be considered limited for the target lines' operation planning because it uses average or standard processing time at the step of operation assignment. Though in this step a good solution can be worked out, after the worker allocation problem is solved, the line balance loss will exactly increase.

In order to verify this hypothesis and clarify the applicable areas of Method B, in the next section, numerical comparisons will be conducted.

4. COMPARATIVE NUMERICAL EXPERIMENT

4.1 Experiment Environment
The verification is undertaken to clarify the performances of the above two methods in the sewing lines, where there are various operations and where skill levels at operations differ largely among workers.

The following three parameters are proposed to represent the varieties of operation and worker ability:

(1) Difference in average processing time among operations (Operation variety 1): Operation variety is large if this difference is large. This parameter is set in three levels: large, medium and small.

(2) Difference in processing time among workers (Operation variety 2): A worker's processing time in a given operation depends on his/her skill level, the degree to which he/she has mastered that operation. This difference in processing time among workers shows the difficulty of an operation. It means the more difficult an operation is, the larger the difference will be. In our target sewing lines, the difficulty of mastering an operation varies among operations. This parameter is also set in three levels: large, medium and small.

(3) Difference in processing abilities among workers (Worker ability variety): Worker ability is evaluated by one's skill levels at all operations. Three kinds of workers exist: A new worker (Type 1) only can process a few operations at a high skill level, while the multi-skilled workers (Type 3) can process almost any operation at a high skill level. The ability of the third kind of worker (Type 2) is between that of the new worker and the skilled worker. Worker variety is small when only one kind of worker exists. This parameter is set in three levels: large, medium and small.

Data and Parameters
- Average processing time of all operations: 30 sec.
- Operation variety 1:
  - Large: ±80% Medium: ±50% Small: ±30%
- Operation variety 2:
  - Large: ±80% Medium: ±50% Small: ±30%
- Worker ability variety:
  - Range of worker skill level at an operation: 0.2-1.8
  - Type 1 Worker skill level range 0.2-1.8
  - Type 2 Worker skill level range 0.5-1.5
  - Type 3 Worker skill level range 0.2-0.8
  - Small: number of Type 1, 2 and 3 = 2:6:2
  - Medium: number of Type 1, 2 and 3 = 3:5:2
  - Large: number of Type 1, 2 and 3 = 5:4:1

Based on the above range, data are created randomly for each examination.

Examination Conditions
- Number of workstations: 10
- Number of operations involved in the product: 10, 30, 50 (3 problems)
- Number of examination cases (e.g., Operation Variety 1: Operation Variety 2: Worker Ability Variety = S:S:S, etc.) for each problem: 27
- Number of examinations for each case: 3-10 (data are re-created each time)

Figure 1 illustrates the precedence diagram of the 30 operations problem.

Figure 1 Precedence Graph

4.2 Experiments on Method A
The algorithms of Method A for each sub-problem are shown as follows:

(1) Algorithm for Operation Assignment
The Helgeson-Birnie approach is adopted [10]. Average processing time of workers is used in the calculation.

(2) Algorithm for Worker Allocation
Step 1:
List all workers and workstations.

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Step 2:
Select the workstation with the highest workload (calculated by workers' average processing time), and assign the worker who can process the operations of that workstation in the shortest processing time. Delete the workstation and the worker from the list.

Step 3:
Repeat Step 2 until all workers are assigned to workstations.

Method A is tested in 27 cases. For each case, 9-30 problems are created.

Results
Line balance loss increases when all varieties turn large (see Figure 2). It is clear that workloads are difficult to balance among workstations without considering worker allocation, because the difference between a worker's processing time and workers' average time (which is used for operation assignment) is large.

Average rate of line balance loss (%)

![Graph showing line balance loss](image)

**Figure 2: Production Environment Comparison**

**4.3 Worker Allocation Algorithm of Method B**
In order to deal with the new production environment (Operation Variety ①: Operation Variety ②: Worker Ability Variety = L:L:L), we suggest a planning procedure (Method B) because it can use each worker's real processing time for operation assignment. However, as this procedure has to determine worker allocation without information on operation assignment, determination policies need to be developed. In this paper, the following 3 factors are considered for worker allocation algorithms.

(i) Worker allocation priority
i-1 A worker is given higher priority whose total processing time of all the operations is shorter
i-2 A worker is given higher priority who can process the operations of a target workstation in the shorter processing time.

(ii) Allocation priority of workstations
ii-1 A workstation is given higher priority which is located nearer the head of the line
ii-2 A workstation is given higher priority whose workload is higher

(iii) Workload estimation
iii-1 Do not estimate workload
iii-2 Estimate workload by considering the operation processing sequence and operation quantity of a workstation.

Based on the above considerations, the following 3 algorithms are proposed for worker allocation:
- Algorithm ① (the combination of i-1 & ii-1 & iii-1)
- Algorithm ② (the combination of i-2 & ii-1 & iii-2)
- Algorithm ③ (the combination of i-2 & ii-2 & iii-2)

Algorithm ① sequences workers in their work abilities, with the aim of easily moving operations between workstations (workers). The determination procedure of this algorithm is simple.

Algorithm ② and ③ both consider workstation workload, and Algorithm ③ aims to allocate the worker with the highest ability to the bottleneck workstation.

From the numerical experiments, Algorithm ③ is proved to produce the best cycle time (see Figure 3). It can be considered that this algorithm focuses on both workload estimation and the bottleneck workstation so that good operation and worker combination may have a good chance of being created. Therefore, Algorithm ③ is adopted as the worker allocation algorithm for Method B.

![Graph showing average CT](image)

**Figure 3: Comparison of Worker Allocation Algorithms**

The details of Algorithm ③ are shown as follows:

**Step 1:**
List all workers and workstations.

**Step 2:**
Use the Helgeson-Bimie approach to decide an operation's assignment priority. Calculate the average operation number of a workstation.
If there exists a remainder, the workstations at the head of a line will be given one more operation.

Step 3:
Temporarily assign the operations to the workstations with the calculated number.

Step 4:
Estimate the workload of each workstation (by calculating workers' average processing time at each workstation).

Step 5:
Select the workstation with the maximum workload, and assign the worker who can process the operations of that workstation in the shortest processing time. Delete the workstation and the worker from the list.

Step 6:
Repeat Step 5 until all workers are assigned to workstations.

The algorithm for operation assignment in Method B uses the same procedure as in Method A. The only difference is that the workload is calculated by using each worker's processing time, instead of average time.

4.4 Experiment on Method B
4.4.1 Comparisons between Method A and B

![Figure 4 Comparison of Cycle Time](image)

![Figure 5 Comparison of Line Balance Loss](image)

Method B is evaluated by comparing it with Method A in several problems; for each problem, cycle time, rate of line balance loss and total processing time are compared. As a result, Method B is confirmed to perform better than Method A under the new production environment (see Figures 4-6); it is especially superior in cycle time and line balance loss for all cases.

![Figure 6 Comparison of Total Processing Time](image)

4.4.2 Discussion of Method B
It is verified that Method B is applicable when both operation variety and worker ability variety are large. Here, another examination is conducted to analyze the effect sensitivity for Method B.

The number of operations (the workload to the line) is changed, and Figure 7 illustrates one example of the results.

![Figure 7 Operation Numbers and Cycle Time](image)

The calculation result of the 30 operations problem is obtained by timing the simulation result of the 15 operations problem. Figure 7 illustrates that the simulation result of 30 is better than the calculation result. That means when the number of operations increases, in other words, when more operations need be assigned, the effect of using Method B on a decreasing cycle time turns large. However, in order to clarify the effective range of the method, more study is needed.

On the other hand, we also examine the possibility improving Method B. It is pointed out that after all operations and workers are assigned to workstations by Method B, the cycle time can still be decreased by changing some worker allocations (Figure 8). Therefore, in order to obtain an optimized solution, Method B still needs to be developed.
Cycle time (sec.)

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Figure 8 Improvement of Method B

5. CONCLUSION

This paper focuses on the product of sewing shops, in which there are various operations for completing a product and the operations combination differs largely among products, and in which skill levels at an operation differ largely among workers. As a basic inquiry into the line operation planning of such lines, this paper focuses on one sub-problem: the line operation planning of a single product.

From our survey, it is clarified there are two typical determination procedures for line operation planning; one is to first assign operations and then assign workers to the workstations of the line (Method A), while the other takes the opposite procedure (Method B). In this paper, Method A is proved to cause large line balance loss and long cycle time when both operation and varieties increase. In order to deal with this new production environment, we suggest Method B, and propose 3 worker allocation algorithms for it. Comparison experiments were conducted, and it was clarified that Method B is effective in both achieving a short line cycle time and balancing the workload among workers. We also indicate that Method B still can be improved by re-allocated workers.

In order to obtain better solutions, algorithms need to be developed, which can simultaneously deal with operation assignment and worker allocation problems. Also, line operation planning for multi-products should be developed.

REFERENCES