An improvement in calculation method for apparel assembly line balancing

F Khosravi¹, ¹, A H Sadeghi¹ & F Jolai²

¹Textile Department, Amirkabir University of Technology, Tehran, Iran
²Department of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran

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A calculation method has been developed to determine the number of workstations and cycle time, considering one machine type at each workstation, normally preferred in apparel industries. The findings are compared with the earlier findings with respect to criterions such as the number of workers, the level of workers' skill, the number of used machine and the number of worker's movement between machines. The results show improvement in line balancing when taking into consideration the machine type feature. Hence, a model is proposed for apparel assembly line balancing to take into consideration the machine type assigned to each workstation so that it has a specific advantage for apparel assembly lines.

Keywords: Assembly line balancing, Apparel industry, Calculation method, Sewing line

1 Introduction

Sewing line involves a set of workstations wherein a specific task is processed according to a specific sequence. Usually, one or more tasks are assigned to a workstation, and several consecutive workstations form as a sewing line. Therefore, the aim of assembly line balancing in sewing lines is to assign tasks to workstations so that the machines of the workstation can perform the assigned tasks with a balanced loading¹.

In apparel industry, the most important and critical section is sewing. This section usually involves a great number of operations each having a short time to perform. Contrary to most equipments in other assembly lines, the sewing machines are stationary and heavy. In many sewing assembly lines one operator is assigned to each workstation for performing several different operations. If these operations require to be performed by different machines, then the assigned operator has to move among the machines. Since this takes a lot of time, it is better that all operations assigned to a workstation are performed by one machine type. In the other words, it is reasonable to consider each machine as a workstation in such assembly lines.

Most of the general assembly line balancing models have not defined a limitation on the type of tools or machines in each workstation which hinders the application of these models in apparel assembly line balancing. Nonetheless efforts have been made to provide solutions for this kind of lines by different researchers. Recently, assembly line balancing with general resource-constrained has been considered by Corominas et al.². Also, Chen et al.¹ have presented a grouping genetic algorithm for assembly line balancing problem of sewing lines in which each task must be assigned to one of the specified set of alternative machines and one machine must be assigned to each workstation. Shumon et al.³ also have presented a layout model for assembly line balancing and compared the new concept and traditional system in a sewing line.

Use of calculating methods in the area of assembly line balancing is so sufficient because of its simplicity, availability and practicality. Nakajima et al.⁴ have proposed a simple calculating method to determine the number of workstations and cycle time. This calculating method is simple and intelligible, but has not been attended to the said feature of apparel assembly lines, i.e. machine type. This also has some disadvantages such as excess time required for moving operator between machines, necessity of multi-skilled operators, requiring more number of machines and thereupon further space. However, besides these disadvantages, developing a new method which could consider the machinery feature...
in balancing apparel assembly line is strongly required. Therefore, the present study was aimed at developing a method for determining the number of workstations and cycle time, considering one machine type at each workstation. These calculating methods are then applied to a sewing process in practical clothes (jeans) making line, to examine the utility and usefulness of these methods.

2 Materials and Methods

2.1 Proposed Calculation Methods

Based on the objective used for performance evaluation, the assembly line balancing problem is classified into three groups, namely (i) determining the minimum number of workstations for a given cycle time, (ii) minimizing the cycle time for a given number of workstations and (iii) maximizing the line efficiency and deciding the number of workstations and cycle time.

The study includes methods for calculating the optimum number of workstations and also the optimum value of cycle time.

2.1.1 Calculating the Optimal Number of Workstations

Optimal number of workstations is determined so that in addition to satisfying the constraints such as technical sequence of tasks and cycle time, the restriction of allocating only one type of machine to each workstation is also fulfilled.

Consideration of this restriction can solve different problems. For example, problems of allocating specific tasks to specific workstations, task grouping according to task skill levels or allocating specific tasks to only a left-of-line or right-of-line station in a two sided assembly lines5.

Assuming that each task can be assigned to each workstation, the minimum number of workstations (Nmin) is obtained by following equation:

\[ N_{\text{min}} = \left\lceil \sum_{i=1}^{m} t_i \right\rceil + 1 \]  

where \( t_i \) is the processing time for task \( i \); and \( \tau \), the time available in each workstation called cycle time.

But the above assumption is possible only when in each workstation the required machines perform all tasks assigned to that workstation. This requires, on the one hand, much traffic of the operator between machines in a workstation and on the other hand, availability of multiple machines in each workstation. In addition, the operator must be able to handle all these machines.

Now, relaxing the above assumption i.e. considering the machine type, the minimum number of workstations required for each type of machine can be calculated separately. For this purpose, one should divide total time of tasks (require by the similar machine to perform) by cycle time and then add one to integer part of this product. Hence, first we calculate the total time of tasks \( (T_j) \) using the following equation:

\[ T_j = \sum_{i=1}^{K} t_{ij} \quad \forall \ j = 1,2,\ldots, m \]  

where \( t_{ij} \) is the processing time for task \( i \) by machine \( j \); \( \forall \ j = 1,2,\ldots, m \); and \( K \), the number of tasks.

Then the minimum number of workstations for each machine is obtained by dividing the products of Eq. (2) by cycle time and adding one to integer part of the product, which results in following equation:

\[ N_j = \left\lceil \frac{T_j}{\tau} \right\rceil + 1 \quad \forall \ j = 1,2,\ldots, m \]  

Maximum number of workstations is equal to the number of tasks, theoretically, according to following equation:

\[ N_{\text{max}} = K \]  

The practical minimum number of workstations is given by the following equation4:

\[ N_{\text{feas}} = \left\{ N(i) \ | \ t_i > \tau \right\} \]  

where \( N(i) \) is the number of \( i \).

The optimum number\(^4\) of workstations (\( N^* \)) is in the range of:

\[ \max (N_{\text{min}}, N_{\text{feas}}) \leq N^* \leq N_{\text{max}} \]
So, the best result is obtained if
\[
\max (N_{\text{min}}, N_{\text{feas}}) = N^* \quad \ldots(8)
\]

2.1.2 Calculating Optimal Cycle Time

Minimizing the cycle time maximizes the production rate or equivalently minimizes the total idle time for the given number of workstations. Assembly of each product unit requires ‘performing a number of tasks with fixed operation times’. Precedence constraints determine the sequence of tasks processing. In our problem, the machine type on which each task must be completed is given. The production period and the quantity of production for each order must also be specified. Knowing this condition, we balance the line with the aim of minimizing the idle time with the given number of workstations. Therefore, we should minimize the cycle time for which the maximum total time of tasks in the workstation is a lower bound.

For minimizing the total idle time (\(\Delta\)), the total sewing time must be equal to the product of workstation number and the cycle time (\(\Delta = 0\)). But as this case is rare, we try to minimize \(\Delta\). So, firstly the rough cycle time was calculated using the following relationship:
\[
\tau_{\text{theo}} = \frac{H}{Q} \quad \ldots(9)
\]

where \(H\) is the production period; and \(Q\), the quantity of production for each order.

Secondly, using the minimum number of workstations obtained from Eqs (3) and (4), the perfectly balanced time is given by the following equation:
\[
\tau_{m} = \frac{\sum_{j=1}^{m} T_j}{N_{j}} \quad \ldots(10)
\]

If \(\tau_{\text{theo}} \leq \tau_{m}\), the calculation is repeated to minimize idle time.

3 Results and Discussion

This study proposes a calculating method to determine the number of workstations and cycle time, considering one machine type in each workstation. With restricting each workstation to one machine type, the proposed calculating method is found to more practical and more coincide with real requirement of apparel industry. The proposed calculating method is based on the method developed by Nakajima et al.\(^4\) and it is regarded as an extension of their method.

3.1 Calculation of Workstation and Cycle Time

A case study considering a jean manufacturer is used to demonstrate the methods to calculate the number of workstations and cycle time. The real sewing system has been used by Nakajima et al.\(^4\). This sewing line produces the workman jeans using conditions as shown in Table 1 and Fig. 1. In Fig. 1, the numbers show the process sequence and are equivalent to the numbers shown in Table 1.

3.1.1 Optimal Number of Workstations

Firstly, theoretical maximum number of workstations in this example is equal to 15.

\(N_{\text{max}} = 15\)

Secondly, Table 2 shows the theoretical minimum number of workstations, as calculated from Eqs (2)-(4), for each machine type and total minimum of workstations.

Also, the practical minimum number of workstations is calculated using the following equation:
\[
N_{\text{feas}} = \{N(i) \mid t_i > 28.5\} = 5
\]

The range of the optimum number of workstations is \(9 \leq N^* \leq 15\). Consequently, the number of workstations is minimum i.e. 9.

In Fig. 2, technical sequence of process is shown. Now, the main problem is how to determine the cycle

![Fig. 1—Sewn points of workman jeans\(^4\)](image-url)
If the maximum station time ($P_{\text{max}}$) is enough to overcome the required production quantity, this time is set as the cycle time. In this example, the maximum time is equal to 57s, and the required production (505 clothes/day) is obtained by Eq (9), as shown below:

\[
57 = \frac{8 \times 3600}{Q} \Rightarrow Q = 505 \text{ clothes/day}
\]

According to Table 2 and the technical sequence in Fig. 2, first allocating the tasks to the workstations is done for $N=9$. But, with the three constraints that are cycle time, technical sequence and machine type, based on the concept of Jackson’s enumeration method and considering the machine type. It is not possible to allocate the tasks to 9 workstations. There are two following feasible combinations with 10 workstations:

![Fig. 2—Technical sequence of process and representation of start and end time.](image)
(1, 5, 11)-(2, 3)-(4, 6)-(9, 10)-(7)-(8)-(12)-(15)-(13)-(14), the relation among time, the number of operator, the number of machine and machine type factors is shown in Fig. 3.

Figure 3 shows that station time does not exceed the cycle time $\tau=57$ s. Hence, the unbalanced time is the same idle time and the number of operators is reduced to 10 from 11 without any changes in the production quantity. Process efficiency is equal to $E = \frac{354.9}{10 \times 57} = 0.62\% (62\%)$

3.1.2 Optimal Cycle Time

Now, suppose the production is performed under the same conditions, with this difference that 11 workers are in the production line and 700 clothes/day are produced (if a workday includes 8 h). In these conditions, the theoretical cycle time $\tau_{theo}$ for 11 workers/day is obtained by Eq. 9 as shown below:

$$\tau_{theo} = \frac{8 \times 3600}{700} = 41.1 \text{s}$$

The minimum workstations number is obtained by Eqs (2)-(4), as 5 types of machines consisting of 1 machine 1, 5 machines 2, 3 machines 3, 1 machine 4 and 1 machine 5 are required. So, the number of required machine is equal to 12 ($N_{min} = \sum_{j=1}^{5} N_j = 12$).

A combination of elemental work is formed with the workstations number whose specifications are given in Table 3. After process formation, the cycle time is again 41.1 s, and also the production quantity will be the desired amount. The efficiency of this process formation is:

$$E = \frac{354.9}{12 \times 41.1} = 0.72\% (72\%)$$

3.2 Computational Results and Comparisons

Table 4 shows a comparison between the result of Nakajima's model and our proposed method. According to the table, the proposed method, in comparison with the primary method, needs 2 less machines and 3 more workers. In the proposed method all workers are one-skilled because of one machine type in each workstation. But, in the primary method, 3 one-skilled workers, 3 two-skilled workers and 1 of three-skilled worker are required. On the other hand, as mentioned in the introduction, in case of existing several types of machines in workstations, it is needed to consider the additional time for moving operators between machines while it is not considered in primary method. But in the proposed method, this requirement is implemented by considering one type of machine in each workstation. If the mentioned time for each movement is an average of 20 s, the cycle time of Nakajima's method will be equivalent to 77.2 s and it means 9 workers are required to produce production quantity similar to its proposed method. To summarize, the proposed method will need 10 workers and 10 machines, whereas Nakajima's method will need 9 workers and 12 machines. The

**Table 3—Combination with 12 workstations and minimum cycle time**

<table>
<thead>
<tr>
<th>Workstation number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine type</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Tasks</td>
<td>1.5</td>
<td>11</td>
<td>2</td>
<td>3.4</td>
<td>6</td>
<td>7</td>
<td>8, 9, 10</td>
<td>8, 9, 10</td>
<td>12, 15</td>
<td>12, 15</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Total task times</td>
<td>25.5</td>
<td>29</td>
<td>31.5</td>
<td>39.3</td>
<td>40.6</td>
<td>14.9</td>
<td>39.95</td>
<td>39.95</td>
<td>40.5</td>
<td>40.5</td>
<td>7.8</td>
<td>6</td>
</tr>
<tr>
<td>The fixed cycle time</td>
<td>41.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unbalanced time</td>
<td>15.6</td>
<td>12.1</td>
<td>9.6</td>
<td>1.8</td>
<td>0.5</td>
<td>26.2</td>
<td>1.15</td>
<td>1.15</td>
<td>0.6</td>
<td>0.6</td>
<td>33.3</td>
<td>35.1</td>
</tr>
<tr>
<td>$\Delta$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>137.7</td>
<td></td>
</tr>
</tbody>
</table>
same comparison can be done when applying the calculating method of cycle time between two mentioned methods. The result of this comparison is shown in Table 5. According to this table, the proposed method in comparison to primary method needs 1 less machine and 3 more workers, but all of them are one-skilled, whereas in the primary method, 1 four-skilled worker, 1 two-skilled worker and 7 one-skilled workers are required. Here also, considering an approximately 20 s for necessary movement between machines, the cycle time based on Nakajima’s method will be equivalent to 77.2 s and it means 13 workers are required to provide the production quantity similar to its proposed method. To summarize, the proposed method will need 12 workers and 12 machines whereas Nakajima’s method will need 13 workers and 13 machines.

4 Conclusion

In this study, Nakajima’s calculation method, which is an accurate, simple and useable method for