(REFEREED RESEARCH)

AN INTEGER MODEL AND A HEURISTIC ALGORITHM FOR THE FLEXIBLE LINE BALANCING PROBLEM

ESNEK HAT DENGELEME PROBLEMİ İÇİN BİR TAMSAYILI MODEL VE BİR SEZGİSEL ALGORİTMA

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ABSTRACT

In this paper, a new approach to respond rapidly changing market demands has been created for the line balancing problem(LBP) having an important role in textile and apparel industry. The material of the study is the operation details that will be balanced the line in the sewing department. Some of the operations can flexibly be assigned to the operators; these are named as flexible operations. The others, non-flexibles, must be performed to the order. The integer mathematical programming is the method of the study. With the operation details of the product to be balanced the line, an integer model finding minimum idle time per operator in a production range have been developed using integer mathematical programming. Besides, because of the NP-hardness of the LBP, a new heuristic algorithm which responds immediately to market demands, has polynomial complexity, and finds the minimum number of operators has been designed. Using the algorithm designed, software has been programmed in C# to be used in the industry and the high-efficiency balancing results obtained by means of the software have been presented for a sample industrial model.

Key Words: Textile and apparel technology, Flexible line balancing problem, Lean production, Heuristic algorithm, Pocket program, Integer programming.

ÖZET

Bu çalışmada, tekstil ve hazır giyim sektöründe önemli bir yeri olan hat dengeleme problemi(LBP) için değişken piyasa taleplerine hızla cevap verebilecek yeni bir yaklaşım oluşturulmuştur. Çalışmanın materyali dikim bölümünde hat dengelemesi yapılacak ürünün operasyon bilgileridir. Bu operasyonların bazıları esnek atanabilme özellikleri içerebilmektedir, bazıları ise mevcut sıralamalarının dışına çıkamazlar. Çalışmada metod olarak tamsayılı matematiksel programlama kullanılmıştır. Hattı dengelenecek üründeki operasyon bilgileri doğrultusunda, esnek bir üretim aralığı kullanarak operatör başına düşen en az boş zamanı arayan bir tamsayılı matematiksel model geliştirilmiştir. Bunun yanında, LBP'nin NP-Zor sınıfta olmasından dolayı, piyasa taleplerine anında cevap verebilecek, polinomiyal karmaşıklığa sahip, minimum operatör sayısını belirleyen ve operatör başına minimum boş zamanı bulan yeni bir sezgisel algoritma tasarlanmıştır. Tasarlanan yeni algoritma ile endüstride kullanılabilecek C# dilinde bir yazılım programlanmış ve bu yazılım yardımıyla örnek bir model için elde edilen yüksek verimlilikli dengeleme sonuçları sunulmuştur.

Anahtar Kelimeler: Tekstil ve konfeksiyon teknolojisi, Esnek hat dengeleme problemi, Yalın üretim, Sezgisel algoritma, Paket program, Tamsayılı programlama

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1. INTRODUCTION

Assembly lines are flow oriented production systems which are still typical in the industrial production of high quantity standardized commodities and even gain importance in low volume production of customized products. An assembly line consists of work stations (operators), the work pieces (operations) and the machines. The operators have been considered to have equally over operations and machines during balancing process. The operations are consecutively launched down the line and are moved from a station to another station. At each station, certain operations are repeatedly performed regarding the cycle time. The decision problem of optimally balancing the assembly work among the stations with respect to some objective is known as the assembly line balancing problem (2).

In textile and apparel industry, there is a seasonal change and plenty of models. Also, the unit time of operations in the models may be different from each other. Consequently, an operator may work on multiple operations or multiple operators can work on an operation during the line balancing. (7, 8)

Lean production is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. Main strategy of the lean production is to improve quality, cost and delivery performance while reducing the flow time. Lean production eliminates the need to keep stocks and aims to enable the low-cost and high-quality production (9, 10).

Under the term assembly line balancing various optimization models have been introduced and discussed in the literature which aim at supporting the decision maker in configuring efficient assembly systems. The LBP has been the subject of interest for nearly 60 years, starting with early problem definitions (3) and the first published paper by Salveson (15). Among many different types of the LBPs, Expert Line Balancing System describes a heuristic and tutorial method and has been computerized so as to act like an expert in an interactive model (12).

New procedures as well as a mathematical model on the single-model assembly line balancing problem with parallel lines are proposed. These procedures are illustrated with numerical examples (6). A branch-and-bound based heuristic is developed for solving large-scale line balancing problems. The heuristic solutions are compared with a lower bound, and experiments show that the heuristic provides much better solutions than those obtained by traditional approaches (4). Also, Becker and Scholl (2) have presented a survey about problems and methods in generalized assembly line balancing.

Kara et al. (11) aimed to achieve main benefits of just-in-time delivery production regarding line balancing and model sequencing with their proposed approach. Time and Space constrained Assembly Line Balancing Problem; as well as a basic model of one of its variants is put forward for study and focuses on the application of a procedure based on ant colonies to solve an assembly line balancing problem (1).

Nuriyev et al. (14) have presented a mathematical programming for determination of optimal production quantity for minimum idle time and a case study has been illustrated in a garment industry.

The LBP is also a combinatorial optimization problem. The LBP is in NP-Hard class and takes exponential time to be solved optimally (5). In this paper, an integer mathematical model including lean production technique has been developed from Nuriyev et al. (14). This model also takes into consideration whether the non-flexible operations in the balancing process are in their order. Besides, new software, based on a new heuristic algorithm, considering flexibilities of the operations and having polynomial complexity to solve the LBP with lean production in textile and apparel industry, has been created.

2. MATERIAL AND METHOD

Sewing department is one of the most important departments in textile and apparel industry. A sufficient line balancing in the sewing department increases the workers' motivation and effectiveness of the establishment (16). Also, lean production technique was used for the line balancing in the department. In this paper, some details of the operations of a product, which are the operation names, the machine names to run the operations, the flexibilities and the unit times, were used as the material for the line balancing in the sewing department (Table 1).

The operations in the balancing process can have flexibility feature. Some operations, named by flexible operations, have flexibility. The flexible operations can flexibly be assigned to the operators and the remaining operations, named by non-flexible operations, have to be performed to the order. There is a wide range of the flexible operations to assign an operator which is advantageous. However, the non-flexible operations have a sorting among themselves so that a non-flexible operation is depended on the previous non-flexible one.

In the LBP, the operations should be assigned to the operators under precedence and flexibility constraints of the operations to balance the line, so that remaining idle time per operator is minimized. In this paper, the LBP was interpreted like the Bin Packing Problem (BPP) and a model was developed using the integer mathematical programming method to solve the LBP optimally. Because the LBP is in NP-Hard class, the optimal solution cannot be always determined as methodically in reasonable time. To solve the LBP faster but near optimal, a new heuristic algorithm, based on BPP-wise algorithms, was created using above-mentioned operation details and the software was programmed in C# programming language.

Table 1. Details of the operations of the sample model

No	Operation Name	Unit Time (cmin.)	Machine Name	Flexibility
1	Sewing dart	88	Lockstitch	False
2	Fusing interlaing for pocket	10	Iron	False
3	Fusing interlaing to the facing	8	Iron	True
4	Making chain stitch to the facing and the other part with overlock	38	Overlock machine with three thread	True
5	Sewing the facing	90	Lockstitch	False
6	Making a notch to the facing	56	Manuel	False
7	Sewing the end of the facing and making top stitch	130	Lockstitch	False
8	Finishing back pocket	78	Lockstitch	False
9	Sewing back pockets bag	24	Overlock machine with five thread	False
10	Making chain stitch to back with overlock	37	Overlock machine with five thread	False
11	Making top stitch to back	39	Lockstitch	False

2.1. The Integer Mathematical Model of the LBP with Lean Production

Suppose that we have a sample model (Table 1) to produce and the model has a number of operations (n), including non-flexible and flexible operations on the line. Let the non-flexible operations are made one by one in the order and the flexible ones can be made anywhere.

In the production process, t_j shows the unit time of operation j and each operator can work $(T + ot)$ unit time as minute at most in a day, where T shows common daily work time and ot shows daily overtime. Operation j will spend $p \cdot t_j$ minutes for p products in the process.

All operations in the process are made in work stations and the work stations are run by operators. For some number of products, the production time of some operations can be too large than the work time of one operator, so these operations cannot be made by an operator in the same day. In this case, second operator or third operator, if needed, is assigned to these operations to solve the time problem. Hence, the operator is named as the work group including one, two or three operators during balancing the line.

If a work group has $l (l \in \mathbb{Z}^+)$ operators, then the capacity of the related group is $l \cdot (T + ot)$ minutes, that is,

$$(l-1) \cdot (T+ot) < p \cdot t_j \leq l \cdot (T+ot) \Rightarrow$$

$$l \textit{ operators are needed } (l \in \mathbb{Z}^+) \quad (2.1)$$

Expression (2.1) says that how many operators are needed to perform operation j. Each operation must be assigned to a particular work group and each work group can have from 1 to l operators. To make useful and more realistic programming, l is bounded by 3.

In mathematical terms, the LBP can be interpreted like the BPP, where the operations and the work groups become the objects and the bins. Although the bins have same capacity in the BPP, the work groups having different capacity will be used in the LBP. (14)

Let m be the number of work groups where $X = (X_1, X_2, \ldots, X_m)$, n be the number of operations where $X_i = (x_{i1}, x_{i2}, \ldots, x_{in}), i = \overline{1,m}$ and s be the number of non-flexible operations.

$t_j \in \mathbb{Z}^+, j = \overline{1,n}$, the unit time of operation j,

$l_i \in \mathbb{Z}^+, i = \overline{1,m}$, the number of operators of work group i,

$e_j \in \mathbb{Z}^+, j = \overline{1,s}$, the index of nonflexible operation j,

$T \in \mathbb{Z}^+$, common daily work time,

$ot \in \mathbb{Z}^+$, daily overtime,

$$x_{ij} = \begin{cases} 1, & \textit{if operation } j \textit{ is assigned to work group } i; \\ 0, & \end{cases}$$

$$i = \overline{1,m}, j = \overline{1,n} \quad \textit{otherwise}.$$

Using above notations and without loss of generality, we will assume that $p \cdot t_j \leq 3 \cdot (T + ot) \textit{ for } \forall j$ and accordingly $1 \leq l_i \leq 3 \textit{ for } \forall i$.

$$C_i = \sum_{j=1}^{n} p \cdot t_j \cdot x_{ij}, \forall i \quad (2.2)$$

$$\Delta C_i = l_i \cdot (T + ot) - C_i, \forall i \quad (2.3)$$

$$\Delta C = \sum_{i=1}^{m} \Delta C_i \quad (2.4)$$

$$\Delta ID = \Delta C / \sum_{i=1}^{m} l_i \quad (2.5)$$

In expressions (2.2-2.6), (2.2) gives the work time of work group i, (2.3) gives the idle time of work group i, (2.4) gives the total idle time of the production process, and (2.5) gives the idle time per operator over the process.

Using above expressions, the Integer Mathematical Program of the LBP, including flexible and non-flexible operations and lean manufacturing, can be modelled as below:

$$\text{Min}_X \, \Delta ID \quad (2.6)$$

subject to

$$\sum_{j=1}^{n} p \cdot t_j \cdot x_{ij} \leq l_i \cdot (T + ot), \forall i \quad (2.7)$$

$$\sum_{i=1}^{m} x_{ij} = 1, \forall j \quad (2.8)$$

$$\sum_{j=1}^{n} x_{ij} \geq 1, \forall i \quad (2.9)$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} = n \quad (2.10)$$

$$l_i = \left\lceil \max_{\forall j} \{ p \cdot t_j \cdot x_{ij} / (T + ot) \} \right\rceil, \forall i \quad (2.11)$$

$$i \cdot x_{ie_j} - k \cdot x_{ke_{j-1}} > 0, i = \overline{1, m-1}, k = \overline{i+1, m}, j = \overline{2, s}, x_{ie_j} = 1 \quad (2.12)$$

$$x_{ij} = 0 \vee 1, \forall i, \forall j \quad (2.13)$$

$$l_i \in \mathbb{Z}^+, \forall i \quad (2.14)$$

The integer mathematical model is (2.6-2.14), where (2.7) shows that operations, which are assigned to the work groups, can't exceed the time capacity of the assigned work group, (2.8) shows that each operation can be only made in one work group, (2.9) shows that each work group have to operate one operation at least, (2.10) shows that all operations must be made during the balancing process, (2.11) determines the number of operators of work group i, and (2.12) checks whether the non-flexible operations are depended on their order. Under the constraints (2.7-2.14), the goal (2.6) is to minimize the idle time per operator.

To find the most efficient production number, the Integer Mathematical Program must be solved for each value in interval $[p - \tilde{p}, p + \tilde{p}]$, where $\tilde{p}$ is flexibility constant. After that, $\hat{p}$, the most suitable production number, is selected and, ΔID, i.e., the minimum average idle time per operator, is determined (14).

2.2. A New Heuristic Algorithm for the LBP with Lean Production

Let m be the number of the work groups and n be the number of operations in the LBP. To solve optimally the LBP, there are n^m possibilities to enumerate and there have been no polynomial algorithms so far for the LBP. Therefore, the LBP needs exponential time and is in NP-Hard class because of polynomial reducibility from the BPP (5).

In industrial practice, a director has to generate a feasible solution in reasonable time and this solution getting from the solution space has to be acceptable, that is, not optimal but near optimal to satisfy the industrial demands. To solve the LBP with lean production in reasonable time and satisfy the demands, a new heuristic algorithm having two main steps has been created in this paper.

Firstly, the non-flexible operations are assigned to the work groups. On this step, procedure **P1**, based on performing Next Fit-wise algorithm for the BPP, has been generated because non-flexible operations have an order in lean production. The complexity of the procedure is $O(n)$ (5, 13).

Procedure P1:

1. *Get* $p, n, T, ot, (t_1, t_2, \dots, t_n)$
2. $i = 1, j = 0, l_i = 1, C_i = 0, U = l_i \cdot (T + ot)$
   for $j = 1$ *to* n *do*
3. *if j is not flexible then*
4. $pt = p \cdot t_j$
5. *if* $pt \geq U$ *then determine* l_i *using expression (2.1) and update* $U = l_i \cdot (T + ot)$
6. *if* $C_i + pt > U$ *then*
   $i = i + 1,\ l_i = 1,\ C_i = 0,\ U = l_i \cdot (T + ot)$
   and GOTO 6
7. $C_i = C_i + pt$
8. *Print*
   $m, (C_1, C_2, \dots, C_m)$ *and* $(l_1, l_2, \dots, l_m)$

On the second step, the remaining ones, the flexible operations, which have no order in the balancing process, are placed to the current suitable work groups using procedure **P2,** produced by First Fit-wise algorithm for the BPP. This procedure has $O(n \cdot lgn)$ complexity (5, 13).

Procedure P2:

1. Get
   $p, n, m, T, ot, (t_1, t_2, \dots, t_n)$,
   $(C_1, C_2, \dots, C_m), (l_1, l_2, \dots, l_m)$
2. *for* $j = 1$ *to* n *do*
3. *if j is flexible then*
4. $pt = p \cdot t_j$
5. *for* $i = 1$ *to* m *do*
6. *if* $C_i + pt \leq l_i \cdot (T + ot)$ *then*
   $C_i = C_i + pt$ *and GOTO 2*
7. *else break*
8. $m = m + 1$, *determine* l_m *using expression (2.1),* $C_m = C_m + pt$
9. *Print*
   $m, (C_1, C_2, \dots, C_m)$ *and* $(l_1, l_2, \dots, l_m)$

Using above procedures **P1** and **P2**, the algorithm of the LBP with lean production can be written as below. The algorithm gives us the suitable product number having the minimum average idle time.

The main algorithm for the LBP with lean production:

1. *Get* $p, \tilde{p}, n, T, ot, (t_1, t_2, \dots, t_n)$
2. $\hat{p} \leftarrow p$
3. *For* $p \leftarrow \hat{p} - \tilde{p}$ *to* $\hat{p} + \tilde{p}$ *do*
4. *Call*
   $\boldsymbol{P1}(p, n, T, ot, (t_1, t_2, \dots, t_n))$
5. $m \leftarrow i$
6. *Call*
   $\boldsymbol{P2}(p, n, m, T, ot, (t_1, t_2, \dots, t_n), (C_1, C_2, \dots, C_m), (l_1, l_2, \dots, l_m))$
7. *Calculate average id per operator as*
   $\sum_{i=1}^{m}\left((T + ot) \cdot l_i - C_i\right) / \sum_{i=1}^{m} l_i$
8. *if new minimum id is found, then set* id_{min} *and related* p_{min},
9. *Print* id_{min} , p_{min}

This algorithm searches the best number of production in the interval $[p - \tilde{p}, p + \tilde{p}]$ where $\tilde{p}$ is pre-defined flexibility constant of production. Along the algorithm, procedures P1 and P2 are executed consecutively at each number of product. The complexity of P1 is $O(n)$ and P2 has $O(nlgn)$. So, the complexity in the main loop of the algorithm is $O(n \cdot lgn)$ $\left(= O(n + n \cdot lgn) = O(n) + O(n \cdot lgn)\right)$ in the sense. Lastly, the main loop of the algorithm runs $(2 \cdot \tilde{p} + 1)$ times $O(n \cdot lgn)$ and the total complexity is $O(\tilde{p} \cdot n \cdot lgn)$ $\left(= O\left((2 \cdot \tilde{p} + 1) \cdot n \cdot lgn\right)\right)$ for the algorithm where $\tilde{p} \ll p$.

3. SOFTWARE AND COMPUTATIONAL EXPERIMENTS

This software coded in C# programming language uses the presented heuristic algorithm and lists all solutions in the given interval of number of productions. After loading details of operations of the sample model (Table 1), the software needs lower number of productions (*P_low*), upper number of productions (*P_up*), common daily work time in minute (*T*), daily overtime in minute (*ot*), and lower bound of efficiency (*e_low*) to balance the line about the sample model (Figure 1). As the result of the software, all suitable numbers of productions (*p*) with the total idle time ($\sum id$), the total work time ($\sum C_i$), the total numbers of operators ($\sum l_i$), the work time per operator ($\sum C_i / \sum l_i$), and related efficiency (ef) are listed. Lastly, the number of production which has best efficiency among the listed numbers is selected. If it is needed, other numbers of productions can be scanned and balanced.

For example, the best efficiency is %97 and the related number of production is 175 in Table 2 and every operator must averagely work 523 minutes along the process. Due to the size of the market demands, balancing in minimum production numbers as *p=175* cannot always satisfy the demands. Hence, the flexibility constant of the number of products must be selected carefully to reach effective results. However, using above results, another feasible solution can be chosen having good efficiency as 91% to satisfy the demands. So, a real life balancing example can be created to be selected *p=739* (Table 3).

Table 2. Available solutions for the sample model and 90% higher efficiency

P	$\sum id$ (min)	$\sum C_i$ (min)	$\sum l_i$	$\sum C_i / \sum l_i$ (min)	ef %
162	111	967	2	483,5	0,9
163	104	974	2	487	0,9
164	98	980	2	490	0,91
165	92	986	2	493	0,91
166	86	992	2	496	0,92
167	80	998	2	499	0,92
168	74	1004	2	502	0,93
169	68	1010	2	505	0,94
170	63	1016	2	508	0,94
171	57	1021	2	510,5	0,95
172	51	1027	2	513,5	0,95
173	45	1033	2	516,5	0,96
174	39	1039	2	519,5	0,96
175	33	1046	2	523	0,97
243	166	1451	3	483,67	0,9
244	159	1458	3	486	0,9
245	153	1464	3	488	0,9
246	147	1470	3	490	0,91
247	141	1476	3	492	0,91
248	135	1482	3	494	0,91
249	129	1488	3	496	0,92
250	125	1495	3	498,33	0,92
728	505	4350	9	483,33	0,9
729	498	4357	9	484,11	0,9
730	493	4363	9	484,78	0,9
731	485	4370	9	485,56	0,9
732	480	4375	9	486,11	0,9
733	475	4380	9	486,67	0,9
734	468	4387	9	487,44	0,9
735	462	4393	9	488,11	0,9
736	456	4399	9	488,78	0,91
737	449	4406	9	489,56	0,91
738	445	4410	9	490	0,91
739	438	4417	9	490,78	0,91

Table 3. The distribution of the operations and the efficiency results for *p=739*

P	$\sum id$	$\sum C_i$	$\sum l_i$	$\sum C_i / \sum l_i$	ef %
739	438	4417	9	490,78	0,91

No	$\sum l_i$	Operations	$\sum C_i$
1	2	1; 2; 3; 4	1064
2	2	5; 6	1078
3	2	7	960
4	2	8; 9; 10	1027
5	1	11	288

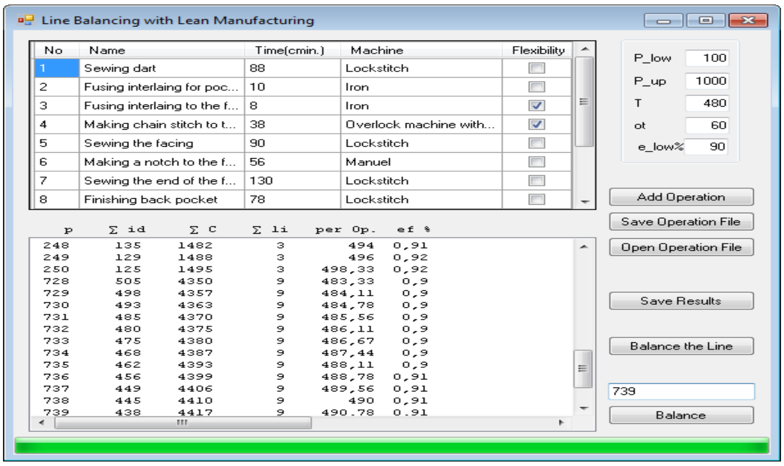

Figure 1. The Software of the LBP with Lean Production

4. CONCLUSION

In this paper, an integer mathematical model have been firstly developed which uses the operation details of a product in the sewing department, takes into consideration flexibility of the operations and the lean production in textile and apparel industry. The goal is to find the minimum idle time per operator and the most efficient number of production found as solving the mathematical model for each value in the interval $[p-\tilde{p}, p+\tilde{p}]$.

Then, a new heuristic algorithm has been presented having $O(nlgn)$ complexity for the LBP with lean production which is in NP-Hard class. The algorithm balances the given operations to the work groups and finds the minimum number of operators.

Finally, the software which solves the LBP with lean production based on the created algorithm has constructed. The software coded in C# programming language finds the minimum idle time per operator and lists all results for the calculated number of productions (Figure 1). These results are the number of production (*p*), total idle time ($\sum id$), total work time ($\sum C_i$), total numbers of operators ($\sum l_i$), work time per operator ($\sum C_i / \sum l_i$), and related efficiency (*ef*). So, users can easily choose desired number of production and balance the line in textile and apparel industry in Table 2 and Figure 1.

The mathematical model, the algorithm and the software can also be used to balance the assembly lines in various industries which contain different operations.

As the future work, new meta-heuristic algorithms, software and new mathematical models adding flexibility bounds will be created to solve the LBP with lean production in textile and apparel industry.

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